**Manual for Curved Beam Model Piston Ring Design Tool (CBM-RDT)**

(Console Version 1.0)

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**Introduction**

Curved Beam Model Ring Design Tool is an analytical tool that can be used in the design process of single-piece piston ring. It consists of 5 prime modules, each corresponding to a function summarized below:

1. Calculate geometric parameters of the ring cross section.
2. Calculate the ring free-shape, its final shape when subjected to a constant radial pressure (this final shape is called ovality) and the force distribution in circular bore. Knowing one of these distributions, this model determines the other two.
3. Calculate the ring-bore and ring-liner conformability: ring-bore and ring-groove interactions include asperity and lubrication forces along with gas, inertia and initial tangential load forces. Bore, groove upper and lower flanks distortions are also considered. Ring thermal expansion effect and radial temperature gradient moment are included in the model. Piston secondary motion and variation of oil viscosity on the liner with its temperature in addition to the existence of fuel spot are considered as well. A radial plot function is made separately to the computation one so that user can define the more convenient graphic parameters for the plot: magnification coefficient for bore distortion and ring-liner clearance, number of forces to represent and the maximum acceptable value to be represented for forces.
4. Conformability module for different ring gap locations defined uniformly along the bore circumferential direction. A radial plot animation function is made separately to the computation one. In addition to the graphic parameters mentioned in point 3, user can choose the number of frames per second for the video that will be created.
5. Calculate the ring static twist under FixOD or FixID constraint that is similar to practical measurement of static twist angle.

The first module is run always and is the first one to be executed. The other modules have independent inputs and outputs. They all require some of the outputs of the geometric parameters of the ring cross-section module as input. The following sections provide a description of these inputs and outputs.

The radial direction will be denoted by y and the axial one by z.

**Module 1: Ring cross-section parameters calculation**

**Inputs**

Ring cross-section can be defined:

1. By giving the points’ coordinates:
   1. By providing the number of points defining the cross section
   2. Then providing the points’ coordinates millimeters and in clockwise order with the outer-diameter (OD) on the left as shown in Figure 1. Each point will have an id.
   3. Provide the id for the upper OD point (#6 in Figure 1), the upper ID (#7 in Figure 1), lower ID (#1 in Figure 1), lower OD (#2 in Figure 1), lower end point (#3 in Figure 1), minimum point (#4 in Figure 1), upper end point (#5 in Figure 1).
   4. Linear coefficients for upper and lower edge factor (denoted by and respectively). Upper and lower edge factor are the linear coefficients in the parabolic shape parts of the running face: between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1) and between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1).



Figure 1

1. By providing the ring cross section parameters listed in the table below and shown in Figure 1.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Upper OD width |  | Positive sign |  |
| Upper OD height |  | Positive sign |  |
| Upper ID width |  | Positive sign |  |
| Upper ID height |  | Positive sign |  |
| Lower ID width |  | Positive sign |  |
| Lower ID height |  | Positive sign |  |
| Lower OD width |  | Positive sign |  |
| Lower OD height |  | Positive sign |  |
| Lower end point width |  | Positive sign |  |
| Lower end point axial location |  | Negative sign |  |
| Minimum point width |  | Positive sign |  |
| Minimum point axial location |  | Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1) |  |
| Upper end point width |  | Positive sign |  |
| Upper end point axial location |  | Positive sign |  |
| Linear coefficient for upper edge shape factor |  |  |  |
| Linear coefficient for lower edge shape factor |  |  |  |

**Outputs**

The outputs differ regarding the inputs provided.

1. If the inputs are defined using method 1, the outputs are the following:

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Center of mass radial coordinate |  | Can be positive or negative based on the points’ coordinates provided |  |
| Center of mass axial coordinate |  | Can be positive or negative based on the points’ coordinates provided |  |
| Upper OD width |  | Positive sign |  |
| Upper OD height |  | Positive sign |  |
| Upper ID width |  | Positive sign |  |
| Upper ID height |  | Positive sign |  |
| Lower ID width |  | Positive sign |  |
| Lower ID height |  | Positive sign |  |
| Lower OD width |  | Positive sign |  |
| Lower OD height |  | Positive sign |  |
| Lower end point width |  | Positive sign |  |
| Lower end point axial location |  | Negative sign |  |
| Minimum point width |  | Positive sign |  |
| Minimum point axial location |  | Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1) |  |
| Upper end point width |  | Positive sign |  |
| Upper end point axial location |  | Positive sign |  |
| Ring upper flank angle |  | Positive sign. Analogous to shown in Figure 2. |  |
| Ring lower flank angle |  | Positive sign. Shown in Figure 2. |  |
| Lower edge width |  | Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Upper edge width |  | Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Quadratic coefficient for upper edge shape factor |  |  |  |
| Quadratic coefficient for lower edge shape factor |  |  |  |
| Cross section area |  |  |  |
| Moment of inertia in plane |  |  |  |
| Moment of inertia out of plane |  |  |  |
| Product of inertia |  |  |  |
| Principal moment of inertia in plane |  |  |  |
| Principal moment of inertia out of plane |  |  |  |
| Principal angle |  |  |  |
| Polar moment of inertia |  |  |  |
| Torsional factor |  |  |  |

1. If the inputs are defined using method 2, the outputs are the following:

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Ring upper flank angle |  | Positive sign. Analogous to shown in Figure 2. |  |
| Ring lower flank angle |  | Positive sign. Shown in Figure 2. |  |
| Lower edge width |  | Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Upper edge width |  | Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Quadratic coefficient for upper edge shape factor |  |  |  |
| Quadratic coefficient for lower edge shape factor |  |  |  |
| Cross section area |  |  |  |
| Moment of inertia in plane |  |  |  |
| Moment of inertia out of plane |  |  |  |
| Product of inertia |  |  |  |
| Principal moment of inertia in plane |  |  |  |
| Principal moment of inertia out of plane |  |  |  |
| Principal angle |  |  |  |
| Polar moment of inertia |  |  |  |
| Torsional factor |  |  |  |

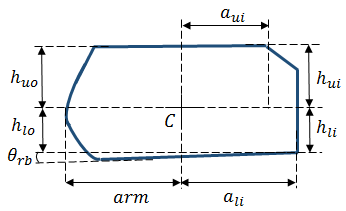


Figure 2

**Module 2: Free-shape, ovality and force distribution in radial bore**

This module consists of 3 sub-models each computing two of the three distributions from the third one. Inputs and outputs of each of these sub-modules are provided below.

**Inputs of sub-model computing the free-shape and the ovality from the force distribution in radial bore**

Inputs that need to be provided by the user.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Bore diameter |  |  |  |
| Ring Young modulus |  |  |  |
| Gap size when ring is closed to circular bore |  |  |  |
| Gap size when ring is closed to ovality (under constant pressure) |  |  |  |
| Force distribution in radial bore |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the pressure times ring height (axial width). | & |
| IsPovAvg |  | 1 to consider the constant linear force in computing the ovality equal to the average of the force distribution in radial bore provided, 0 to provide its value (). |  |
| Constant linear force to consider in computing the ovality (pressure times the ring height (axial width)) |  | Positive sign. User needs to provide this value only when IsPovAvg=0. |  |
| Number of elements for the FEM |  | Positive integer |  |
| Number of points within one element |  | Positive integer |  |
| Tolerance for Newton-Raphson algorithm convergence used to compute the ovality |  | Positive sign. Suggested value: |  |
| Maximum number of Newton-Raphson algorithm iterations used to compute the ovality |  | Positive integer. Suggested value: |  |
| Magnifying coefficient for the radial plot of the ovality |  | Positive sign.  Suggested values: in order of |  |

Inputs provided by the ring cross-section parameters calculation module.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Moment of inertia in plane |  |  |  |
| Minimum point width |  |  |  |

**Outputs of sub-model computing the free-shape and the ovality from the force distribution in radial bore**

Two text files are generated:

* fs\_frompr.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the free-shape in usual representation in millimeters.
* rov\_frompr.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the ovality in usual representation in millimeters.

Three plots are generated:

* Curve of the free-shape in usual representation in millimeters as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
* Radial plot of the ovality (closed shape of the ring under the constant pressure).
* Curve of the ovality in usual representation in microns as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.

**Inputs of sub-model computing the force distribution in radial bore and ovality from the free-shape**

Inputs that need to be provided by the user.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Bore diameter |  |  |  |
| IsBDist |  | 1 to take into account bore distortion when computing the force distribution in radial bore, 0 otherwise |  |
| Highest order in the Fourier series for bore distortion. |  | Non-zero positive integer. User has to provide this value if IsBDist=1. |  |
| Ampdata |  | 1 to provide the amplitudes and phases of bore distortion directly, 0 to provide dr distribution. User has to provide this value if IsBDist=1. |  |
| Amplitudes for bore distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,Norderth amplitudes). User has to provide this value if IsBDist=1 and Ampdata=1. |  |
| Phases for bore distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,Norderth phases). User has to provide this value if IsBDist=1 and Ampdata=1. |  |
| Bore distortion distribution dr |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the bore distortion dr in microns. User has to provide this value if IsBDist=1 and Ampdata=0. | & |
| Gap size when ring is closed to circular bore |  |  |  |
| Gap size when ring is closed to ovality (under constant pressure) |  |  |  |
| Ring density |  |  |  |
| Ring Young modulus |  |  |  |
| Ring Poisson ratio |  |  |  |
| Ring thermal expansion coefficient |  |  |  |
| Ring gap position |  | Ring gap position in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) |  |
| Ring temperature |  |  |  |
| Number of elements for the FEM |  | Positive integer |  |
| Number of points within one element |  | Positive integer |  |
| Liner Young modulus |  |  |  |
| Liner Poisson ratio |  |  |  |
| Plateau ratio |  |  |  |
| Liner surface roughness standard deviation |  |  |  |
| Piston upper land reference diameter |  |  |  |
| Ring groove root diameter |  |  |  |
| Piston lower land reference diameter |  |  |  |
| Ring groove inner axial height |  |  |  |
| Ring groove upper flank angle |  |  |  |
| Ring groove lower flank angle |  |  |  |
| Ring groove upper flank surface roughness standard deviation |  |  |  |
| Ring groove lower flank surface roughness standard deviation |  |  |  |
| Groove Poisson ratio |  |  |  |
| Groove Young modulus |  |  |  |
| Radius increase at the upper land during engine operation |  |  |  |
| Radius increase at the lower land during engine operation |  |  |  |
| Top ring groove radius increase during engine operation |  |  |  |
| z coefficient for the asperity ring/liner and ring/groove contact interaction |  | 6.804 is the adopted value in the simplified formulation |  |
| K coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1.198e-4 is the adopted value in the simplified formulation |  |
| A coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4.4068e-5 is the adopted value in the simplified formulation |  |
| coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4 is the adopted value in the simplified formulation |  |
| Friction coefficient for the asperity ring/liner and ring/groove contact interaction |  |  |  |
| Constant coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1 is the adopted value in the simplified formulation |  |
| IsGDist |  | 1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise |  |
| Number of orders starting from the 2nd one in the Fourier series for groove upper flank distortion |  | Non-zero positive integer. User has to provide this value if IsGDist=1. |  |
| Ampdatau |  | 1 to provide the amplitudes and phases of groove upper flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsBDist=1. |  |
| Amplitudes for groove upper flank distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,th amplitudes). User has to provide this value if IsGDist=1 and Ampdatau=1. |  |
| Phases for groove upper flank distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,th phases). User has to provide this value if IsBDist=1 and Ampdatau=1. |  |
| Groove upper flank distortion distribution dz |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove upper flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatau=0. | & |
| Number of orders starting from the 2nd one in the Fourier series for groove lower flank distortion |  | Non-zero positive integer. User has to provide this value if IsGDist=1. |  |
| Ampdatal |  | 1 to provide the amplitudes and phases of ring lower flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsGDist=1. |  |
| Amplitudes for groove lower flank distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,th amplitudes). User has to provide this value if IsGDist=1 and Ampdatal=1. |  |
| Phases for groove lower flank distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,th phases). User has to provide this value if IsGDist=1 and Ampdatal=1. |  |
| Groove lower flank distortion distribution dz |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove lower flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatal=0. | & |
| Groove thermal tilting – upper flank |  |  |  |
| Groove thermal tilting – lower flank |  |  |  |
| IsPovAvg |  | 1 to consider the constant linear force in computing the ovality equal to the average of the force distribution in radial bore that will be computed, 0 to provide its value () |  |
| Constant linear force to consider in computing the ovality (pressure times the ring height (axial width)) |  | Positive sign. User needs to provide this value only when IsPovAvg=0. |  |
| IsFreeshape |  | 1 to provide the free-shape coordinates and 0 to provide the free-shape curvature |  |
| Free-shape distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape coordinates in usual representation in millimeters. User has to provide this value if IsFreeshape=1. | & |
| Free-shape curvature distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape curvature coordinates in usual representation in 1/m. User has to provide this value if IsFreeshape=0. | & |
| Tolerance for Newton-Raphson algorithm convergence used to compute the force distribution |  | Positive sign. Suggested value: |  |
| Maximum number of Newton-Raphson algorithm iterations used to compute the force distribution |  | Positive integer. Suggested value: |  |
| Tolerance for Newton-Raphson algorithm convergence used to compute the ovality |  | Positive sign. Suggested value: |  |
| Maximum number of Newton-Raphson algorithm iterations used to compute the ovality |  | Positive integer. Suggested value: |  |
| Magnifying coefficient for the radial plot of the ovality |  | Positive sign.  Suggested values: in order of |  |

Inputs provided by the ring cross-section parameters calculation module.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Upper OD width |  | Positive sign |  |
| Upper OD height |  | Positive sign |  |
| Upper ID width |  | Positive sign |  |
| Upper ID height |  | Positive sign |  |
| Lower ID width |  | Positive sign |  |
| Lower ID height |  | Positive sign |  |
| Lower OD width |  | Positive sign |  |
| Lower OD height |  | Positive sign |  |
| Ring upper flank angle |  | Positive sign. Analogous to shown in Figure 2. |  |
| Ring lower flank angle |  | Positive sign. Shown in Figure 2. |  |
| Lower edge width |  | Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Upper edge width |  | Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Minimum point axial location |  | Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1) |  |
| Quadratic coefficient for upper edge shape factor |  |  |  |
| Quadratic coefficient for lower edge shape factor |  |  |  |
| Linear coefficient for upper edge shape factor |  |  |  |
| Linear coefficient for lower edge shape factor |  |  |  |
| Minimum point width |  | Positive sign |  |
| Cross section area |  |  |  |
| Principal moment of inertia in plane |  |  |  |
| Principal moment of inertia out of plane |  |  |  |
| Moment of inertia in plane |  |  |  |
| Principal angle |  |  |  |
| Polar moment of inertia |  |  |  |
| Torsional factor |  |  |  |

**Outputs of sub-model computing the force distribution in radial bore and ovality from the free-shape**

Two text files are generated:

* rforce\_fromfs.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the radial linear force in N/m.
* rov\_fromfs.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the ovality in usual representation in millimeters.

Three plots are generated:

* Curve of the radial linear force in N/m as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
* Radial plot of the ovality (closed shape of the ring under the constant pressure).
* Curve of the ovality in usual representation in microns as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.

The code also displays the tangential load determined from the force distribution computed.

**Inputs of sub-model computing the force distribution in radial bore and free-shape from the ovality**

Inputs that need to be provided by the user.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Bore diameter |  |  |  |
| Ring Young modulus |  |  |  |
| Gap size when ring is closed to circular bore |  |  |  |
| Gap size when ring is closed to ovality (under constant pressure) |  |  |  |
| Number of elements for the FEM |  | Positive integer |  |
| Number of points within one element |  | Positive integer |  |
| Ovality distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the ovality radial coordinates in usual representation in microns. | & |
| Constant linear force to consider in computing the ovality (pressure times the ring height (axial width)) |  | Positive sign. |  |
| IsBDist |  | 1 to take into account bore distortion when computing the force distribution in radial bore, 0 otherwise |  |
| Highest order in the Fourier series for bore distortion. |  | Non-zero positive integer. User has to provide this value if IsBDist=1. |  |
| Ampdata |  | 1 to provide the amplitudes and phases of bore distortion directly, 0 to provide dr distribution. User has to provide this value if IsBDist=1. |  |
| Amplitudes for bore distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,Norderth amplitudes). User has to provide this value if IsBDist=1 and Ampdata=1. |  |
| Phases for bore distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,Norderth phases). User has to provide this value if IsBDist=1 and Ampdata=1. |  |
| Bore distortion distribution dr |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the bore distortion dr in microns. User has to provide this value if IsBDist=1 and Ampdata=0. | & |
| Ring density |  |  |  |
| Ring Poisson ratio |  |  |  |
| Ring thermal expansion coefficient |  |  |  |
| Ring gap position |  | Ring gap position in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) |  |
| Ring temperature |  |  |  |
| Liner Young modulus |  |  |  |
| Liner Poisson ratio |  |  |  |
| Plateau ratio |  |  |  |
| Liner surface roughness standard deviation |  |  |  |
| Piston upper land reference diameter |  |  |  |
| Ring groove root diameter |  |  |  |
| Piston lower land reference diameter |  |  |  |
| Ring groove inner axial height |  |  |  |
| Ring groove upper flank angle |  |  |  |
| Ring groove lower flank angle |  |  |  |
| Ring groove upper flank surface roughness standard deviation |  |  |  |
| Ring groove lower flank surface roughness standard deviation |  |  |  |
| Groove Poisson ratio |  |  |  |
| Groove Young modulus |  |  |  |
| Radius increase at the upper land during engine operation |  |  |  |
| Radius increase at the lower land during engine operation |  |  |  |
| Top ring groove radius increase during engine operation |  |  |  |
| z coefficient for the asperity ring/liner and ring/groove contact interaction |  | 6.804 is the adopted value in the simplified formulation |  |
| K coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1.198e-4 is the adopted value in the simplified formulation |  |
| A coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4.4068e-5 is the adopted value in the simplified formulation |  |
| coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4 is the adopted value in the simplified formulation |  |
| Friction coefficient for the asperity ring/liner and ring/groove contact interaction |  |  |  |
| Constant coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1 is the adopted value in the simplified formulation |  |
| IsGDist |  | 1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise |  |
| Number of orders starting from the 2nd one in the Fourier series for groove upper flank distortion |  | Non-zero positive integer. User has to provide this value if IsGDist=1. |  |
| Ampdatau |  | 1 to provide the amplitudes and phases of groove upper flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsBDist=1. |  |
| Amplitudes for groove upper flank distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,th amplitudes). User has to provide this value if IsGDist=1 and Ampdatau=1. |  |
| Phases for groove upper flank distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,th phases). User has to provide this value if IsBDist=1 and Ampdatau=1. |  |
| Groove upper flank distortion distribution dz |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove upper flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatau=0. | & |
| Number of orders starting from the 2nd one in the Fourier series for groove lower flank distortion |  | Non-zero positive integer. User has to provide this value if IsGDist=1. |  |
| Ampdatal |  | 1 to provide the amplitudes and phases of ring lower flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsGDist=1. |  |
| Amplitudes for groove lower flank distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,th amplitudes). User has to provide this value if IsGDist=1 and Ampdatal=1. |  |
| Phases for groove lower flank distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,th phases). User has to provide this value if IsGDist=1 and Ampdatal=1. |  |
| Groove lower flank distortion distribution dz |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove lower flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatal=0. | & |
| Groove thermal tilting – upper flank |  |  |  |
| Groove thermal tilting – lower flank |  |  |  |
| Tolerance for Newton-Raphson algorithm convergence used to compute the force distribution |  | Positive sign. Suggested value: |  |
| Maximum number of Newton-Raphson algorithm iterations used to compute the force distribution |  | Positive integer. Suggested value: |  |

Inputs provided by the ring cross-section parameters calculation module.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Upper OD width |  | Positive sign |  |
| Upper OD height |  | Positive sign |  |
| Upper ID width |  | Positive sign |  |
| Upper ID height |  | Positive sign |  |
| Lower ID width |  | Positive sign |  |
| Lower ID height |  | Positive sign |  |
| Lower OD width |  | Positive sign |  |
| Lower OD height |  | Positive sign |  |
| Ring upper flank angle |  | Positive sign. Analogous to shown in Figure 2. |  |
| Ring lower flank angle |  | Positive sign. Shown in Figure 2. |  |
| Lower edge width |  | Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Upper edge width |  | Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Minimum point axial location |  | Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1) |  |
| Quadratic coefficient for upper edge shape factor |  |  |  |
| Quadratic coefficient for lower edge shape factor |  |  |  |
| Linear coefficient for upper edge shape factor |  |  |  |
| Linear coefficient for lower edge shape factor |  |  |  |
| Minimum point width |  | Positive sign |  |
| Cross section area |  |  |  |
| Principal moment of inertia in plane |  |  |  |
| Principal moment of inertia out of plane |  |  |  |
| Moment of inertia in plane |  |  |  |
| Principal angle |  |  |  |
| Polar moment of inertia |  |  |  |
| Torsional factor |  |  |  |

**Outputs of sub-model computing the force distribution in radial bore and free-shape from the ovality**

Two text files are generated:

* rforce\_fromov.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the radial linear force in N/m.
* fs\_fromov.txt containing two columns: 1st column contains the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one the free-shape in usual representation in millimeters.

Three plots are generated:

* Curve of the free-shape in usual representation in millimeters as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
* Curve of the radial linear force in N/m as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.

The code also displays the tangential load determined from the force distribution computed.

**Module 3: Calculate the ring-bore and ring-liner conformability for specific ring gap location**

This module consists of 2 sub-models. The first one performs the computation related to the conformability study for one specific ring gap position. The second one uses the result of the first sub-model to generate the radial plots. Inputs and outputs of each of these sub-modules are provided below.

**Inputs of sub-model performing the computation related to the conformability study for one specific ring gap location**

Inputs that need to be provided by the user.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| IsBDist |  | 1 to take into account bore distortion when computing the force distribution in radial bore, 0 otherwise |  |
| IsPTilt |  | 1 to take into account piston dynamic tilt, 0 otherwise |  |
| IsGDist |  | 1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise |  |
| IsFreeshape |  | 1 to provide the free-shape coordinates or curvature and 0 to provide the radial pressure distribution for the circular bore |  |
| Bore diameter |  |  |  |
| Gap size when ring is closed to circular bore |  |  |  |
| Ring Young modulus |  |  |  |
| Ring density |  |  |  |
| Ring Poisson ratio |  |  |  |
| Ring thermal expansion coefficient |  |  |  |
| Ring gap position |  | Ring gap position in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) |  |
| Ring temperature |  |  |  |
| Ring temperature increase from ID to OD distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the radial ring temperature increase from ID to OD in Celsius. | & |
| Number of elements for the FEM |  | Positive integer |  |
| Number of points within one element for contact and lubrication force calculation |  | Positive integer |  |
| Number of points within one element for gas force calculation |  | Positive integer |  |
| Highest order in the Fourier series for bore distortion. |  | Non-zero positive integer. User has to provide this value if IsBDist=1. |  |
| Ampdata |  | 1 to provide the amplitudes and phases of bore distortion directly, 0 to provide dr distribution. User has to provide this value if IsBDist=1. |  |
| Amplitudes for bore distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,Norderth amplitudes). User has to provide this value if IsBDist=1 and Ampdata=1. |  |
| Phases for bore distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,Norderth phases). User has to provide this value if IsBDist=1 and Ampdata=1. |  |
| Bore distortion distribution dr |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the bore distortion dr in microns. User has to provide this value if IsBDist=1 and Ampdata=0. | & |
| Piston tilt angle |  | User has to provide this value if IsPTilt=1. |  |
| Piston offset |  | Positive sign. |  |
| zk coefficient for oil viscosity calculation |  |  |  |
| Temp1 variable for oil viscosity calculation |  |  |  |
| Temp2 variable for oil viscosity calculation |  |  |  |
| Oil density |  |  |  |
| hlratio coefficient for oil viscosity calculation |  |  |  |
| Beta1 coefficient for oil viscosity calculation |  |  |  |
| Beta2 coefficient for oil viscosity calculation |  |  |  |
| Viscosity of oil located within the groove |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the viscosity of oil located within the groove in Pa.s. | & |
| Liner Young modulus |  |  |  |
| Liner Poisson ratio |  |  |  |
| Plateau ratio |  |  |  |
| Liner surface roughness standard deviation |  |  |  |
| Piston upper land reference diameter |  |  |  |
| Ring groove root diameter |  |  |  |
| Piston lower land reference diameter |  |  |  |
| Ring groove inner axial height |  |  |  |
| Ring groove upper flank angle |  |  |  |
| Ring groove lower flank angle |  |  |  |
| Ring groove upper flank surface roughness standard deviation |  |  |  |
| Ring groove lower flank surface roughness standard deviation |  |  |  |
| Groove Poisson ratio |  |  |  |
| Groove Young modulus |  |  |  |
| Radius increase at the upper land during engine operation |  |  |  |
| Radius increase at the lower land during engine operation |  |  |  |
| Top ring groove radius increase during engine operation |  |  |  |
| z coefficient for the asperity ring/liner and ring/groove contact interaction |  | 6.804 is the adopted value in the simplified formulation |  |
| K coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1.198e-4 is the adopted value in the simplified formulation |  |
| A coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4.4068e-5 is the adopted value in the simplified formulation |  |
| coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4 is the adopted value in the simplified formulation |  |
| Friction coefficient for the asperity ring/liner and ring/groove contact interaction |  |  |  |
| Constant coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1 is the adopted value in the simplified formulation |  |
| IsGDist |  | 1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise |  |
| Number of orders starting from the 2nd one in the Fourier series for groove upper flank distortion |  | Non-zero positive integer. User has to provide this value if IsGDist=1. |  |
| Ampdatau |  | 1 to provide the amplitudes and phases of groove upper flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsBDist=1. |  |
| Amplitudes for groove upper flank distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,th amplitudes). User has to provide this value if IsGDist=1 and Ampdatau=1. |  |
| Phases for groove upper flank distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,th phases). User has to provide this value if IsBDist=1 and Ampdatau=1. |  |
| Groove upper flank distortion distribution dz |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove upper flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatau=0. | & |
| Number of orders starting from the 2nd one in the Fourier series for groove lower flank distortion |  | Non-zero positive integer. User has to provide this value if IsGDist=1. |  |
| Ampdatal |  | 1 to provide the amplitudes and phases of ring lower flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsGDist=1. |  |
| Amplitudes for groove lower flank distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,th amplitudes). User has to provide this value if IsGDist=1 and Ampdatal=1. |  |
| Phases for groove lower flank distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,th phases). User has to provide this value if IsGDist=1 and Ampdatal=1. |  |
| Groove lower flank distortion distribution dz |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove lower flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatal=0. | & |
| Groove thermal tilting – upper flank |  |  |  |
| Groove thermal tilting – lower flank |  |  |  |
| Minimum oil film thickness to consider for liner lubrication |  | Suggested value: half the liner surface standard deviation () |  |
| Lubrication cases threshold |  | Ratio between oil film thickness on liner by liner surface roughness standard deviation to consider as threshold between partially and fully flooded lubrication cases. Suggested value: 10 |  |
| Viscosity factor for fuel spots |  | Factor by which the oil viscosity should be divided in regions where we have fuel spots. Suggested value: 100 |  |
| Gas pressure in groove upper region distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove upper region in Bar. | & |
| Gas pressure in groove inner region distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove inner region in Bar. | & |
| Gas pressure in groove lower region distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove lower region in Bar. | & |
| Piston speed |  | The axial axis is positively pointing upwards. |  |
| Piston acceleration |  | The axis is positively pointing upwards |  |
| Oil film thickness left on liner into the ring distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness left on liner into the ring in microns. | & |
| Oil film thickness on the upper groove flank distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness on the upper groove flank in microns. | & |
| Oil film thickness on the lower groove flank distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness on the lower groove flank in microns. | & |
| Liner temperature distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the temperature liner in Celsius. This temperature distribution will be used to compute oil viscosity. | & |
| Fuel spots distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the fuel spots (1 for existence of fuel, 0 for non-existence). | & |
| b coefficient for fully flooded correlation |  | Suggested value: 2.1 |  |
| c coefficient for fully flooded correlation |  | Suggested value: 0.102 |  |
| d coefficient for fully flooded correlation |  | Suggested value: -0.04 |  |
| e coefficient for fully flooded correlation |  | Suggested value: 0.90229 |  |
| Correlation pressure for deterministic partially flooded forces |  | Suggested value: 398.56 |  |
| Correlation exponent for deterministic partially flooded forces |  | Suggested value: 2.523 |  |
| Reference viscosity for deterministic partially flooded forces |  | Suggested value: 1.5e-2 |  |
| ap coefficient for deterministic partially flooded forces |  | Suggested value: 0.039342 |  |
| cp1 coefficient for exponent Kp in deterministic partially flooded forces |  | Suggested value: -2.965331 |  |
| cp2 coefficient for exponent Kp in deterministic partially flooded forces |  | Suggested value: 1.499148 |  |
| F0 coefficient for deterministic partially flooded shear force |  | Suggested value: 0.098577 |  |
| cf1 coefficient for exponent Kp in deterministic partially flooded forces |  | Suggested value: -0.383954 |  |
| cf2 coefficient for exponent Kp in deterministic partially flooded forces |  | Suggested value: 0.138443 |  |
| Ring width to use for the deterministic hydrodynamic correlation |  |  |  |
| IsFreeshaped |  | 1 to provide the free-shape coordinates and 0 to provide the free-shape curvature. User has to provide this value if IsFreeshape=1. |  |
| Free-shape distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape coordinates in usual representation in millimeters. User has to provide this value if IsFreeshape=1 and IsFreeshaped=1. | & |
| Free-shape curvature distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape curvature coordinates in usual representation in 1/m. User has to provide this value if IsFreeshape=1 and Isfreeshaped=0. | & |
| Force distribution in radial bore |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the pressure times ring height (axial width). User has to provide this value if IsFreeshape=0. | & |
| Tolerance for Newton-Raphson algorithm convergence |  | Positive sign. Suggested value: |  |
| Maximum number of Newton-Raphson algorithm iterations |  | Positive integer. Suggested value: |  |

Inputs provided by the ring cross-section parameters calculation module.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Upper OD width |  | Positive sign |  |
| Upper OD height |  | Positive sign |  |
| Upper ID width |  | Positive sign |  |
| Upper ID height |  | Positive sign |  |
| Lower ID width |  | Positive sign |  |
| Lower ID height |  | Positive sign |  |
| Lower OD width |  | Positive sign |  |
| Lower OD height |  | Positive sign |  |
| Ring upper flank angle |  | Positive sign. Analogous to shown in Figure 2. |  |
| Ring lower flank angle |  | Positive sign. Shown in Figure 2. |  |
| Lower edge width |  | Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Upper edge width |  | Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Minimum point axial location |  | Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1) |  |
| Quadratic coefficient for upper edge shape factor |  |  |  |
| Quadratic coefficient for lower edge shape factor |  |  |  |
| Linear coefficient for upper edge shape factor |  |  |  |
| Linear coefficient for lower edge shape factor |  |  |  |
| Minimum point width |  | Positive sign |  |
| Cross section area |  |  |  |
| Principal moment of inertia in plane |  |  |  |
| Principal moment of inertia out of plane |  |  |  |
| Moment of inertia in plane |  |  |  |
| Moment of inertia out of plane |  |  |  |
| Principal angle |  |  |  |
| Polar moment of inertia |  |  |  |
| Torsional factor |  |  |  |

**Outputs of sub-model performing the computation related to the conformability study for one specific ring gap location**

One text file is generated res\_conf\_one\_gap.txt. It contains 20 columns, specified below from the left to the right:

* Column 1: Circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for the ring’s coordinates and clearances results from column 2 to column 10.
* Column 2: Ring liner clearance in microns. Always non-negative.
* Column 3: Ring neutral axis lift in microns. The zero level is located at the middle of the groove inner region. The axial axis is positively pointing upwards.
* Column 4: Ring radial coordinate in microns. This is defined respect to the nominal radius defined by . A positive radial coordinate means that the ring cross-section centroid is located outside the circle with a radius equal to the nominal one.
* Column 5: Ring twist angle in degrees. A positive ring twist angle means the ring cross section is rotated in the clockwise direction with the ring’s outer-diameter (OD) on the left as shown in Figure 1 and Figure 2.
* Column 6: Minimum liner clearance point location with respect to the centroid in microns. A positive sign means that this point is located above the centroid axial level.
* Column 7: Upper OD point clearance with the groove in microns. Always non-negative.
* Column 8: Upper ID point clearance with the groove in microns. Always non-negative.
* Column 9: Lower OD point clearance with the groove in microns. Always non-negative.
* Column 10: Lower ID point clearance with the groove in microns. Always non-negative.
* Column 11: Circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for forces, moments and stresses results from column 12 to column 20.
* Column 12: Radial force in N/m (force per unit circumferential length of the ring). A positive sign corresponds to a compression force.
* Column 13: Ring-liner radial force in N/m (force per unit circumferential length of the ring).
* Column 14: Axial force in N/m (force per unit circumferential length of the ring). The axial axis is positively pointing upwards.
* Column 15: Twist moment in N (moment per unit circumferential length of the ring). The angular orientation is positive in the clockwise direction with the ring’s outer-diameter (OD) on the left as shown in Figure 1 and Figure 2.
* Column 16: Bending moment at the ring cross-section centroid in Nm.
* Column 17: Stress at upper OD point in MPa. A positive sign corresponds to extension.
* Column 18: Stress at upper ID point in MPa. A positive sign corresponds to extension.
* Column 19: Stress at lower OD point in MPa. A positive sign corresponds to extension.
* Column 20: Stress at lower ID point in MPa. A positive sign corresponds to extension.

Six plots are generated:

* The first one contains the curve of the ring-liner clearance and the ring radial coordinate as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. Both are plotted in microns.
* The second plot gives the curve of the ring neutral axis lift and the minimum liner clearance point location with respect to the centroid as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. Both are given in microns. It also gives the ring twist angle in degrees as a function of the same circumferential direction angles in degrees.
* The third plot displays the 4 curves of lower/upper OD/ID clearances with the groove, all in microns and as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
* The fourth plot contains the curve of the radial force, ring-liner radial force and axial one all in N/m as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. It also gives the twist moment in N as a function of the same circumferential direction angles in degrees.
* The fifth plot gives the bending moment at the ring cross-section centroid in Nm as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
* The sixth plot displays the 4 curves of stresses at lower/upper OD/ID points all in MPa as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.

The code also displays the tangential load determined from the force distribution computed.

**Inputs of sub-model performing the radial plots related to the conformability study for one specific ring gap location**

Inputs that need to be provided by the user.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Magnification coefficient for radial plot of bore distortion and ring liner clearance |  | Positive sign. Suggested value: 3000 |  |
| Number of radial forces to represent |  | Positive integer. Suggested value: 200 |  |
| Maximum acceptable value for forces to be represented |  | Positive sign. |  |

This code also uses bore distortion, FEM related, ring gap size, ring-liner clearance, radial force and ring-liner force inputs and outputs of the sub-model performing the computation related to the conformability study for one specific ring gap location.

**Outputs of sub-model performing the radial plots related to the conformability study for one specific ring gap location**

Two plots are generated:

* The first one contains radial plot of the bore and the ring with the specified magnification coefficient. It also contains scaled lines showing the ring-liner forces based on the number of forces to be represented and the maximum acceptable value specified. It also displays separate message(s) if the bore or/and the ring is(are) misrepresented because of the magnification coefficient. It also shows the ring gap location within the bore fixed reference from thrust to thrust side and shows a message in case the force is truncated somewhere based on the maximum acceptable value for force to be represented that has been chosen.
* The second one contains radial plot of the bore and the ring with the specified magnification coefficient. It also contains scaled lines showing the radial forces based on the number of forces to be represented and the maximum acceptable value specified. It also displays separate message(s) if the bore or/and the ring is(are) misrepresented because of the magnification coefficient. It also shows the ring gap location within the bore fixed reference from thrust to thrust side and shows a message in case the force is truncated somewhere based on the maximum acceptable value for force to be represented that has been chosen.

**Module 4: Calculate the ring-bore and ring-liner conformability for different ring gap locations**

This module consists of 2 sub-models. The first one performs the computation related to the conformability study for different ring gap positions. The second one uses the result of the first sub-model to generate the radial plots. Inputs and outputs of each of these sub-modules are provided below.

**Inputs of sub-model performing the computation related to the conformability study for different ring gap locations**

Inputs that need to be provided by the user.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| IsBDist |  | 1 to take into account bore distortion when computing the force distribution in radial bore, 0 otherwise |  |
| IsPTilt |  | 1 to take into account piston dynamic tilt, 0 otherwise |  |
| IsGDist |  | 1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise |  |
| IsFreeshape |  | 1 to provide the free-shape coordinates or curvature and 0 to provide the radial pressure distribution for the circular bore |  |
| Bore diameter |  |  |  |
| Gap size when ring is closed to circular bore |  |  |  |
| Ring Young modulus |  |  |  |
| Ring density |  |  |  |
| Ring Poisson ratio |  |  |  |
| Ring thermal expansion coefficient |  |  |  |
| Ring temperature |  |  |  |
| Ring temperature increase from ID to OD distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the radial ring temperature increase from ID to OD in Celsius. | & |
| Number of elements for the FEM |  | Positive integer |  |
| Number of points within one element for contact and lubrication force calculation |  | Positive integer |  |
| Number of points within one element for gas force calculation |  | Positive integer |  |
| Highest order in the Fourier series for bore distortion. |  | Non-zero positive integer. User has to provide this value if IsBDist=1. |  |
| Ampdata |  | 1 to provide the amplitudes and phases of bore distortion directly, 0 to provide dr distribution. User has to provide this value if IsBDist=1. |  |
| Amplitudes for bore distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,Norderth amplitudes). User has to provide this value if IsBDist=1 and Ampdata=1. |  |
| Phases for bore distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,Norderth phases). User has to provide this value if IsBDist=1 and Ampdata=1. |  |
| Bore distortion distribution dr |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the bore distortion dr in microns. User has to provide this value if IsBDist=1 and Ampdata=0. | & |
| Piston tilt angle |  | User has to provide this value if IsPTilt=1. |  |
| Piston offset |  | Positive sign. |  |
| zk coefficient for oil viscosity calculation |  |  |  |
| Temp1 variable for oil viscosity calculation |  |  |  |
| Temp2 variable for oil viscosity calculation |  |  |  |
| Oil density |  |  |  |
| hlratio coefficient for oil viscosity calculation |  |  |  |
| Beta1 coefficient for oil viscosity calculation |  |  |  |
| Beta2 coefficient for oil viscosity calculation |  |  |  |
| Viscosity of oil located within the groove |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the viscosity of oil located within the groove in Pa.s. | & |
| Liner Young modulus |  |  |  |
| Liner Poisson ratio |  |  |  |
| Plateau ratio |  |  |  |
| Liner surface roughness standard deviation |  |  |  |
| Piston upper land reference diameter |  |  |  |
| Ring groove root diameter |  |  |  |
| Piston lower land reference diameter |  |  |  |
| Ring groove inner axial height |  |  |  |
| Ring groove upper flank angle |  |  |  |
| Ring groove lower flank angle |  |  |  |
| Ring groove upper flank surface roughness standard deviation |  |  |  |
| Ring groove lower flank surface roughness standard deviation |  |  |  |
| Groove Poisson ratio |  |  |  |
| Groove Young modulus |  |  |  |
| Radius increase at the upper land during engine operation |  |  |  |
| Radius increase at the lower land during engine operation |  |  |  |
| Top ring groove radius increase during engine operation |  |  |  |
| z coefficient for the asperity ring/liner and ring/groove contact interaction |  | 6.804 is the adopted value in the simplified formulation |  |
| K coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1.198e-4 is the adopted value in the simplified formulation |  |
| A coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4.4068e-5 is the adopted value in the simplified formulation |  |
| coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4 is the adopted value in the simplified formulation |  |
| Friction coefficient for the asperity ring/liner and ring/groove contact interaction |  |  |  |
| Constant coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1 is the adopted value in the simplified formulation |  |
| IsGDist |  | 1 to take into account groove distortion when computing the force distribution in radial bore, 0 otherwise |  |
| Number of orders starting from the 2nd one in the Fourier series for groove upper flank distortion |  | Non-zero positive integer. User has to provide this value if IsGDist=1. |  |
| Ampdatau |  | 1 to provide the amplitudes and phases of groove upper flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsBDist=1. |  |
| Amplitudes for groove upper flank distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,th amplitudes). User has to provide this value if IsGDist=1 and Ampdatau=1. |  |
| Phases for groove upper flank distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,th phases). User has to provide this value if IsBDist=1 and Ampdatau=1. |  |
| Groove upper flank distortion distribution dz |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove upper flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatau=0. | & |
| Number of orders starting from the 2nd one in the Fourier series for groove lower flank distortion |  | Non-zero positive integer. User has to provide this value if IsGDist=1. |  |
| Ampdatal |  | 1 to provide the amplitudes and phases of ring lower flank distortion directly, 0 to provide dz distribution. User has to provide this value if IsGDist=1. |  |
| Amplitudes for groove lower flank distortion |  | Positive values. Number of amplitudes to provide is equal to (0th, 2nd,…,th amplitudes). User has to provide this value if IsGDist=1 and Ampdatal=1. |  |
| Phases for groove lower flank distortion |  | Number of phases to provide is equal to ( 2nd,3rd,…,th phases). User has to provide this value if IsGDist=1 and Ampdatal=1. |  |
| Groove lower flank distortion distribution dz |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the groove lower flank distortion dz in microns. User has to provide this value if IsGDist=1 and Ampdatal=0. | & |
| Groove thermal tilting – upper flank |  |  |  |
| Groove thermal tilting – lower flank |  |  |  |
| Minimum oil film thickness to consider for liner lubrication |  | Suggested value: half the liner surface standard deviation () |  |
| Lubrication cases threshold |  | Ratio between oil film thickness on liner by liner surface roughness standard deviation to consider as threshold between partially and fully flooded lubrication cases. Suggested value: 10 |  |
| Viscosity factor for fuel spots |  | Factor by which the oil viscosity should be divided in regions where we have fuel spots. Suggested value: 100 |  |
| Gas pressure in groove upper region distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove upper region in Bar. | & |
| Gas pressure in groove inner region distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove inner region in Bar. | & |
| Gas pressure in groove lower region distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the gas pressure in groove lower region in Bar. | & |
| Piston speed |  | The axial axis is positively pointing upwards. |  |
| Piston acceleration |  | The axis is positively pointing upwards |  |
| Oil film thickness left on liner into the ring distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness left on liner into the ring in microns. | & |
| Oil film thickness on the upper groove flank distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness on the upper groove flank in microns. | & |
| Oil film thickness on the lower groove flank distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the oil film thickness on the lower groove flank in microns. | & |
| Liner temperature distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the temperature liner in Celsius. This temperature distribution will be used to compute oil viscosity. | & |
| Fuel spots distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the cylinder from thrust side (0°) to thrust side (360°) and the second one contains the fuel spots (1 for existence of fuel, 0 for non-existence). | & |
| b coefficient for fully flooded correlation |  | Suggested value: 2.1 |  |
| c coefficient for fully flooded correlation |  | Suggested value: 0.102 |  |
| d coefficient for fully flooded correlation |  | Suggested value: -0.04 |  |
| e coefficient for fully flooded correlation |  | Suggested value: 0.90229 |  |
| Correlation pressure for deterministic partially flooded forces |  | Suggested value: 398.56 |  |
| Correlation exponent for deterministic partially flooded forces |  | Suggested value: 2.523 |  |
| Reference viscosity for deterministic partially flooded forces |  | Suggested value: 1.5e-2 |  |
| ap coefficient for deterministic partially flooded forces |  | Suggested value: 0.039342 |  |
| cp1 coefficient for exponent Kp in deterministic partially flooded forces |  | Suggested value: -2.965331 |  |
| cp2 coefficient for exponent Kp in deterministic partially flooded forces |  | Suggested value: 1.499148 |  |
| F0 coefficient for deterministic partially flooded shear force |  | Suggested value: 0.098577 |  |
| cf1 coefficient for exponent Kp in deterministic partially flooded forces |  | Suggested value: -0.383954 |  |
| cf2 coefficient for exponent Kp in deterministic partially flooded forces |  | Suggested value: 0.138443 |  |
| Ring width to use for the deterministic hydrodynamic correlation |  |  |  |
| IsFreeshaped |  | 1 to provide the free-shape coordinates and 0 to provide the free-shape curvature. User has to provide this value if IsFreeshape=1. |  |
| Free-shape distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape coordinates in usual representation in millimeters. User has to provide this value if IsFreeshape=1 and IsFreeshaped=1. | & |
| Free-shape curvature distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape curvature coordinates in usual representation in 1/m. User has to provide this value if IsFreeshape=1 and Isfreeshaped=0. | & |
| Force distribution in radial bore |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the pressure times ring height (axial width). User has to provide this value if IsFreeshape=0. | & |
| Tolerance for Newton-Raphson algorithm convergence |  | Positive sign. Suggested value: |  |
| Maximum number of Newton-Raphson algorithm iterations |  | Positive integer. Suggested value: |  |
| Number of ring gap positions equally spaced between 0 and 359 degrees within bore fixed reference from thrust to thrust side to consider |  | Positive integer |  |

Inputs provided by the ring cross-section parameters calculation module.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Upper OD width |  | Positive sign |  |
| Upper OD height |  | Positive sign |  |
| Upper ID width |  | Positive sign |  |
| Upper ID height |  | Positive sign |  |
| Lower ID width |  | Positive sign |  |
| Lower ID height |  | Positive sign |  |
| Lower OD width |  | Positive sign |  |
| Lower OD height |  | Positive sign |  |
| Ring upper flank angle |  | Positive sign. Analogous to shown in Figure 2. |  |
| Ring lower flank angle |  | Positive sign. Shown in Figure 2. |  |
| Lower edge width |  | Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Upper edge width |  | Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Minimum point axial location |  | Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1) |  |
| Quadratic coefficient for upper edge shape factor |  |  |  |
| Quadratic coefficient for lower edge shape factor |  |  |  |
| Linear coefficient for upper edge shape factor |  |  |  |
| Linear coefficient for lower edge shape factor |  |  |  |
| Minimum point width |  | Positive sign |  |
| Cross section area |  |  |  |
| Principal moment of inertia in plane |  |  |  |
| Principal moment of inertia out of plane |  |  |  |
| Moment of inertia in plane |  |  |  |
| Moment of inertia out of plane |  |  |  |
| Principal angle |  |  |  |
| Polar moment of inertia |  |  |  |
| Torsional factor |  |  |  |

**Outputs of sub-model performing the computation related to the conformability study for different ring gap locations**

20 text files are generated. They are specified below:

* res\_theer.txt: Contains one column with the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for the ring’s coordinates and clearances results given in the text files: ”res\_hmin.txt”, ”res\_zr.txt”, ”res\_yr.txt”, ”res\_alr.txt”, ”res\_z0.txt”, ”res\_uoc.txt”, ”res\_uic.txt”, ”res\_loc.txt”, ”res\_lic.txt”.
* res\_hmin.txt: Ring liner clearance in microns. Always non-negative. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_theer.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_zr.txt: Ring neutral axis lift in microns. The zero level is located at the middle of the groove inner region. The axial axis is positively pointing upwards. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_theer.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_yr.txt: Ring radial coordinate in microns. This is defined respect to the nominal radius defined by . A positive radial coordinate means that the ring cross-section centroid is located outside the circle with a radius equal to the nominal one. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_theer.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_alr.txt: Ring twist angle in degrees. A positive ring twist angle means the ring cross section is rotated in the clockwise direction with the ring’s outer-diameter (OD) on the left as shown in Figure 1 and Figure 2. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_theer.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_z0.txt: Minimum liner clearance point location with respect to the centroid in microns. A positive sign means that this point is located above the centroid axial level. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_theer.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_uoc.txt: Upper OD point clearance with the groove in microns. Always non-negative. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_theer.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_uic.txt: Upper ID point clearance with the groove in microns. Always non-negative. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_theer.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_loc.txt: Lower OD point clearance with the groove in microns. Always non-negative. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_theer.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_lic.txt: Lower ID point clearance with the groove in microns. Always non-negative. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_theer.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_thee.txt: Contains one column with the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for forces, moments and stresses results given in the text files: ”res\_fy.txt”, ”res\_fl.txt”, ”res\_fz.txt”, ”res\_m.txt”, ”res\_Mfinal.txt”, ”res\_S\_uo.txt”, ”res\_S\_lo.txt”, ”res\_S\_ui.txt”, ”res\_S\_li.txt”.
* res\_fy.txt: Radial force in N/m (force per unit circumferential length of the ring). A positive sign corresponds to a compression force. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_fl.txt: Ring-liner radial force in N/m (force per unit circumferential length of the ring). It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_fz.txt: Axial force in N/m (force per unit circumferential length of the ring). The axial axis is positively pointing upwards. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_m.txt: Twist moment in N (moment per unit circumferential length of the ring). The angular orientation is positive in the clockwise direction with the ring’s outer-diameter (OD) on the left as shown in Figure 1 and Figure 2. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_Mfinal.txt: Bending moment at the ring cross-section centroid in Nm. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_S\_uo.txt: Stress at upper OD point in MPa. A positive sign corresponds to extension. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_S\_ui.txt: Stress at upper ID point in MPa. A positive sign corresponds to extension. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_S\_lo.txt: Stress at lower OD point in MPa. A positive sign corresponds to extension. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.
* res\_S\_li.txt: Stress at lower ID point in MPa. A positive sign corresponds to extension. It has columns. Each column contains the distribution corresponding to the circumferential direction angles in degrees given in “res\_thee.txt” i.e. each column corresponds to the result obtained for a specific ring gap location among the equally spaced values between 0 (first column) and 359 (last column) degrees within bore fixed reference from thrust to thrust side that were considered.

**Inputs of sub-model performing the radial plots related to the conformability study for different ring gap locations**

Inputs that need to be provided by the user.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Magnification coefficient for radial plot of bore distortion and ring liner clearance |  | Positive sign. Suggested value: 3000 |  |
| Number of radial forces to represent |  | Positive integer. Suggested value: 200 |  |
| Maximum acceptable value for forces to be represented |  | Positive sign. |  |
| Frame rate of the animation for the total radial force |  | Number of frames per second for the video that will be generated. Suggested value: 1 |  |
| Frame rate of the animation for the ring-liner radial force |  | Number of frames per second for the video that will be generated. Suggested value: 1 |  |

This code also uses bore distortion, FEM related, ring gap size, ring-liner clearance, radial force and ring-liner force inputs and outputs of the sub-model performing the computation related to the conformability study for different ring gap locations.

**Outputs of sub-model performing the radial plots related to the conformability study for different ring gap locations**

Two videos are generated:

* The first one contains a fix radial plot of the bore and a moving one the ring based on its gap location using the specified magnification coefficient. For each ring gap location, it plots scaled lines showing the ring-liner forces based on the number of forces to be represented and the maximum acceptable value specified. For each ring gap location, it also displays separate message(s) if the bore or/and the ring is(are) misrepresented because of the magnification coefficient. It also shows the ring gap location within the bore fixed reference from thrust to thrust side and shows a message in case the force is truncated somewhere based on the maximum acceptable value for force to be represented that has been chosen.
* The second one contains a fix radial plot of the bore and a moving one the ring based on its gap location using the specified magnification coefficient. For each ring gap location, it plots scaled lines showing the radial forces based on the number of forces to be represented and the maximum acceptable value specified. For each ring gap location, it also displays separate message(s) if the bore or/and the ring is(are) misrepresented because of the magnification coefficient. It also shows the ring gap location within the bore fixed reference from thrust to thrust side and shows a message in case the force is truncated somewhere based on the maximum acceptable value for force to be represented that has been chosen.

**Module 5: Ring static twist under FixOD or FixID constraint**

This module performs the computation related to ring static twist under FixOD or FixID constraint. Inputs and outputs provided below.

**Inputs**

Inputs that need to be provided by the user.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| IsFreeshape |  | 1 to provide the free-shape coordinates or curvature and 0 to provide the radial pressure distribution for the circular bore |  |
| Bore diameter |  |  |  |
| Gap size when ring is closed to circular bore |  |  |  |
| Ring Young modulus |  |  |  |
| Ring density |  |  |  |
| Ring Poisson ratio |  |  |  |
| Ring thermal expansion coefficient |  |  |  |
| Number of elements for the FEM |  | Positive integer |  |
| Number of points within one element for contact and lubrication force calculation |  | Positive integer |  |
| Liner Young modulus |  |  |  |
| Liner Poisson ratio |  |  |  |
| Plateau ratio |  |  |  |
| Liner surface roughness standard deviation |  |  |  |
| z coefficient for the asperity ring/liner and ring/groove contact interaction |  | 6.804 is the adopted value in the simplified formulation |  |
| K coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1.198e-4 is the adopted value in the simplified formulation |  |
| A coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4.4068e-5 is the adopted value in the simplified formulation |  |
| coefficient for the asperity ring/liner and ring/groove contact interaction |  | 4 is the adopted value in the simplified formulation |  |
| Friction coefficient for the asperity ring/liner and ring/groove contact interaction |  |  |  |
| Constant coefficient for the asperity ring/liner and ring/groove contact interaction |  | 1 is the adopted value in the simplified formulation |  |
| IsFreeshaped |  | 1 to provide the free-shape coordinates and 0 to provide the free-shape curvature. User has to provide this value if IsFreeshape=1. |  |
| Free-shape distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape coordinates in usual representation in millimeters. User has to provide this value if IsFreeshape=1 and IsFreeshaped=1. | & |
| Free-shape curvature distribution |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the free-shape curvature coordinates in usual representation in 1/m. User has to provide this value if IsFreeshape=1 and Isfreeshaped=0. | & |
| Force distribution in radial bore |  | Text file with the first column containing the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring and the second one contains the pressure times ring height (axial width). User has to provide this value if IsFreeshape=0. | & |
| Tolerance for Newton-Raphson algorithm convergence |  | Positive sign. Suggested value: |  |
| Maximum number of Newton-Raphson algorithm iterations |  | Positive integer. Suggested value: |  |

Inputs provided by the ring cross-section parameters calculation module.

|  |  |  |  |
| --- | --- | --- | --- |
| Nomenclature | Variable designation | Comment | Unit |
| Upper OD width |  | Positive sign |  |
| Upper OD height |  | Positive sign |  |
| Upper ID width |  | Positive sign |  |
| Upper ID height |  | Positive sign |  |
| Lower ID width |  | Positive sign |  |
| Lower ID height |  | Positive sign |  |
| Lower OD width |  | Positive sign |  |
| Lower OD height |  | Positive sign |  |
| Ring upper flank angle |  | Positive sign. Analogous to shown in Figure 2. |  |
| Ring lower flank angle |  | Positive sign. Shown in Figure 2. |  |
| Lower edge width |  | Positive sign. Axial distance between lower end point (#3 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Upper edge width |  | Positive sign. Axial distance between upper end point (#5 in Figure 1) and minimum point (#4 in Figure 1) |  |
| Minimum point axial location |  | Positive sign if minimum point located above the gravity center point of the cross section and negative otherwise (negative sign in Figure 1) |  |
| Quadratic coefficient for upper edge shape factor |  |  |  |
| Quadratic coefficient for lower edge shape factor |  |  |  |
| Linear coefficient for upper edge shape factor |  |  |  |
| Linear coefficient for lower edge shape factor |  |  |  |
| Minimum point width |  | Positive sign |  |
| Cross section area |  |  |  |
| Principal moment of inertia in plane |  |  |  |
| Principal moment of inertia out of plane |  |  |  |
| Moment of inertia in plane |  |  |  |
| Principal angle |  |  |  |
| Polar moment of inertia |  |  |  |
| Torsional factor |  |  |  |

**Outputs**

One text file is generated res\_stat\_twist.txt. It contains 9 columns, specified below from the left to the right:

* Column 1: Circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. This angles distribution will be used for the ring’s coordinates, clearances, forces and moment results from column 2 to column 9.
* Column 2: Ring radial coordinate in microns. This is defined respect to the nominal radius defined by . A positive radial coordinate means that the ring cross-section centroid is located outside the circle with a radius equal to the nominal one.
* Column 3: Ring liner clearance in microns. Always non-negative.
* Column 4: Ring twist angle in degrees. A positive ring twist angle means the ring cross section is rotated in the clockwise direction with the ring’s outer-diameter (OD) on the left as shown in Figure 1 and Figure 2.
* Column 5: Lower OD point clearance with the groove in microns. Always non-negative.
* Column 6: Lower ID point clearance with the groove in microns. Always non-negative.
* Column 7: Radial force in N/m (force per unit circumferential length of the ring). A positive sign corresponds to a compression force.
* Column 8: Axial force in N/m (force per unit circumferential length of the ring). The axial axis is positively pointing upwards.
* Column 9: Twist moment in N (moment per unit circumferential length of the ring). The angular orientation is positive in the clockwise direction with the ring’s outer-diameter (OD) on the left as shown in Figure 1 and Figure 2.

Three plots are generated:

* The first one contains the curve of the ring radial coordinate and the ring-liner clearance as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. Both are plotted in microns. It also gives the ring twist angle in degrees as a function of the same circumferential direction angles in degrees.
* The second plot displays the 2 curves of lower OD/ID clearances with the lower plate, both in microns and as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring.
* The third plot contains the curve of the radial force and axial one, both in N/m as a function of the circumferential direction angles in degrees defined with respect to the fixed frame with respect to the ring. It also gives the twist moment in N as a function of the same circumferential direction angles in degrees.

The code also displays the tangential load determined from the force distribution computed.