Appendix D: Systems of Units

The data input in ***DyRoBeS*** is not restricted to a specific system of units. In addition to the consistent units of user's choice, four sets of system of units have been introduced in ***DyRoBeS***:

System of Units
Unit = 0 => Consistent Units of User's Choice
Unit = 1 => Consistent English Units (sec, in, Lbf, Lbf-s^2/in)
Unit = 2 => Engineering English Units (sec, in, Lbf, Lbm)
Unit = 3 => Consistent SI Units (sec, m, N, kg)
Unit = 4 => Engineering Metric Units (sec, mm, N, kg)

For Unit =0, consistent units, it is essential that all of the input parameters be expresses in a consistent set of units of the user's choice. For Unit =1 and 3, these are two sets of consistent units. For Unit =2 and 4, these are two sets of inconsistent units that are commonly used in the engineering field. Since they are not consistent units, their input units are explicitly specified on the input screen. Users must pay attention to their units.

Units Systems	Consistent English Unit = 1	Engineering English Unit = 2	Consistent SI Unit = 3	Engineering Metric Unit = 4
Basic Quantities				
Time	Second (s)	Second (s)	Second (s)	Second (s)
Length	in	in	m	**mm**
Force	Lbf	Lbf	Newton (N)	Newton (N)
Mass	Lbf-s^2/in	**Lbm**	kg = N-s^2/m	**kg**
Inputs				
Material Properties				
Density	Lbf-s^2/in^4	**Lbm/in^3**	kg/m^3	**kg/m^3**
Modulus	Lbf/in^2 (psi)	Lbf/in^2 (psi)	N/m^2 (Pa)	N/mm^2 (MPa)
Shaft Elements				
Length, Diameter	in	in	m	mm
Disks				
Mass	Lbf-s^2/in	**Lbm**	kg	**kg**
Inertia	Lbf-s^2-in	**Lbm-in^2**	kg-m^2	**kg-m^2**
Skew Angle	Degree	Degree	Degree	Degree
Unbalance				
Imbalance (*me*)	Lbf-s^2	**oz-in**	kg-m	**kg-mm**
Angle	Degree	Degree	Degree	Degree
Flexible Supports				
Mass	Lbf-s^2/in	**Lbm**	kg	**kg**
Damping	Lbf-s/in	Lbf-s/in	N-s/m	N-s/mm
Stiffness	Lbf/in	Lbf/in	N/m	N/mm
Forces/Moments				
Forces	Lbf	Lbf	N	N
Moments/Torque	Lbf-in	Lbf-in	N-m	**N-mm**

Misalignment/Bow				
Deflection: x, y	in	in	m	mm
Theta: x, y	degree	degree	degree	degree
Time Forcing				
Force or Moment	Lbf Lbf-in	Lbf Lbf-in	N N-m	N N-mm
Time Constant	1/s	1/s	1/s	1/s
Excitation Freq.	rpm	rpm	rpm	rpm
ϕ - Phase	degree	degree	degree	degree
Bearings - Lateral				
Stiffness – Kt	Lbf/in	Lbf/in	N/m	N/mm
Damping – Ct	Lbf-s/in	Lbf-s/in	N-s/m	N-s/mm
Stiffness – Kr	Lbf-in/rad	Lbf-in/rad	N-m/rad	N-mm/rad
Damping – Cr	Lbf-in-s/rad	Lbf-in-s/rad	N-m-s/rad	N-mm-s/rad
Length	in	in	m	**mm**
Lubricant Viscosity	Reyn (Lbf-s/in^2)	Reyn (Lbf-s/in^2)	Pascal-second (N-s/m^2)	**CentiPoise** =1.0E03 * Pa-s
Lubricant Density	Lbf-s^2/in^4	**Lbm/in^3**	kg/m^3	**kg/m^3**
Pressure Drop Across seal	Psi	Psi	Pa	Bar =1.0E-05 * Pa
Linear PID + Low Pass Filter Active Magnetic Bearings				
Proportional Gain	Lbf/in	Lbf/in	N/m	N/mm
Integral Gain	Lbf/(in-s)	Lbf/(in-s)	N/(m-s)	N/(mm-s)
Derivative Gain	Lbf-s/in	Lbf-s/in	N-s/m	N-s/mm
Cut-Off Freq.	Hz	Hz	Hz	Hz
Non-Linear Active Magnetic Bearings				
Proportional Gain	A/in	A/in	A/m	A/mm
Integral Gain	A/(in-s)	A/(in-s)	A/(m-s)	A/(mm-s)
Derivative Gain	A-s/in	A-s/in	A-s/m	A-s/mm
Force Constant	Lbf-in^2/A^2	Lbf-in^2/A^2	N-m^2/A^2	N-mm^2/A^2
Air Nominal Gap	in	in	m	mm
Current	A	A	A	A
Torsional				
Stiffness – K	Lbf-in/rad	Lbf-in/rad	N-m/rad	N-mm/rad
Damping – C	Lbf-in-s/rad	Lbf-in-s/rad	N-m-s/rad	N-mm-s/rad
Axial				
Stiffness – K	Lbf/in	Lbf/in	N/m	N/mm
Damping – C	Lbf-s/in	Lbf-s/in	N-s/m	N-s/mm
Gravity - g_o	386.088 in/s^2	386.088 in/s^2	9.8066 m/ s^2	9806.6 mm/s^2
Outputs				
Displacements	in	in	m	mm
Velocity	in/s	in/s	m/s	mm/s
Acceleration	in/s^2	in/s^2	m/s^2	mm/s^2
Rotations	rad	rad	rad	rad
Force	Lbf	Lbf	N	N
Moments/Torque	Lbf-in	Lbf-in	N-m	N-mm

The conversions between English and Metric units are list below for quick reference.

Unit	**English**	**Metric**	**Conversions** (* = multiply)
Time	second (s)	second (s)	
Length	in	mm	mm = 25.4 * in
	in	m	m = 0.0254 * in
Force	Lbf	Newton (N)	N = 4.448222 * Lbf
Moment	Lbf-in	N-m	N-m = 0.1129846 * Lbf-in
Density	Lbf-s^2/in^4	kg/m^3	kg/m^3 = 2.767990E+04 * Lbm/in^3 = 1.068688E+07 * Lbf-s^2/in^4
Mass	Lbf-s^2/in	kg = N-s^2/m	kg = 175.1266 * Lbf-s^2/in = 0.4535924 * Lbm
Inertia	Lbf-s^2-in	kg-m^2	kg-m^2 = 0.1129846 * Lbf-s^2-in
Moduli	Lbf/in^2 (psi)	kN/m^2 (kPa) N/m^2 (Pa)	kPa = 6.894757 * psi Pa = 6.894757E+03 * psi
Temperature	^{o}F	^{o}C	^{o}C = (^{o}F-32) * 5/9
Viscosity	Reyn (Lbf-s/in^2)	centiPoise	cP = 6.894757E06 * Reyn
Flow Rate	GPM (gal/min)	m^3/hour	m^3/hour = 0.2271 * GPM
Power	hp (horsepower)	kWatt	kWatt = 0.7457 * hp
Stiffness	Lbf/in	N/mm	N/mm = 0.1751266 * Lbf/in
Damping	Lbf-s/in	N-s/mm	N-s/mm = 0.1751266 * Lbf-s/in
Torsional K	Lbf-in/rad	N-m/rad	N-m/rad = 0.1129846 * Lbf-in/rad
Gravity - g	386.088 in/s^2	9.8066 m/s^2	
Misc.			
			Lbm = 386.088 * Lbf-s^2/in
			1 N = 1kg * 1m/s^2
			cP = grams/CC * cSt (mm^2/s)

The units conversion can be easily implemented by the displacement and force units in the equation of motion:

$$M\ddot{x} + C\dot{x} + Kx = F$$

For Unit = 0, 1, and 3, no data conversion is required. They are consistent units.

For Unit 1 and 2: English Units

The displacement and force units are:

$$\boldsymbol{x} = \begin{Bmatrix} x \\ y \\ \theta_x \\ \theta_y \end{Bmatrix} \quad \text{unit} = \begin{Bmatrix} in \\ in \\ 1 \\ 1 \end{Bmatrix}, \qquad \boldsymbol{F} = \begin{Bmatrix} F_x \\ F_y \\ M_x \\ M_y \end{Bmatrix} \quad \text{unit} = \begin{Bmatrix} Lb_f \\ Lb_f \\ Lb_f - in \\ Lb_f - in \end{Bmatrix},$$

$$\boldsymbol{M} = \begin{bmatrix} Lb_f - s^2/in & & & \\ & Lb_f - s^2/in & & \\ & & Lb_f - in - s^2 & \\ & & & Lb_f - in - s^2 \end{bmatrix}$$

$$\boldsymbol{C} = \begin{bmatrix} Lb_f - s/in & & & \\ & Lb_f - s/in & & \\ & & Lb_f - in - s & \\ & & & Lb_f - in - s \end{bmatrix}$$

$$\boldsymbol{K} = \begin{bmatrix} Lb_f/in & & & \\ & Lb_f/in & & \\ & & Lb_f - in & \\ & & & Lb_f - in \end{bmatrix}$$

To convert Lbm: $Lb_f - s^2/in = \dfrac{Lb_m}{386.088}$

To convert oz-in: $Lb_f - s^2 = \dfrac{oz - in}{386.088 \times 16}$

For Unit 3, Consistent SI Units (sec, m, N, kg), no data conversion is required.

The displacement and force units are:

$$\boldsymbol{x} = \begin{Bmatrix} x \\ y \\ \theta_x \\ \theta_y \end{Bmatrix} \quad \text{unit} = \begin{Bmatrix} m \\ m \\ 1 \\ 1 \end{Bmatrix}, \qquad \boldsymbol{F} = \begin{Bmatrix} F_x \\ F_y \\ M_x \\ M_y \end{Bmatrix} \quad \text{unit} = \begin{Bmatrix} N \\ N \\ N - m \\ N - m \end{Bmatrix},$$

$$\boldsymbol{M} = \begin{bmatrix} kg & & & \\ & kg & & \\ & & kg - m^2 & \\ & & & kg - m^2 \end{bmatrix} \qquad \text{Note:} \quad kg = N - s^2/m$$

$$\boldsymbol{C} = \begin{bmatrix} N-s/m & & & \\ & N-s/m & & \\ & & N-m-s & \\ & & & N-m-s \end{bmatrix}$$

$$\boldsymbol{K} = \begin{bmatrix} N/m & & & \\ & N/m & & \\ & & N-m & \\ & & & N-m \end{bmatrix}$$

For Unit 4, Engineering Metric Units (sec, mm, N, kg), data conversion is required.

The displacement and force units are:

$$\boldsymbol{x} = \begin{Bmatrix} x \\ y \\ \theta_x \\ \theta_y \end{Bmatrix} \quad \text{unit} = \begin{Bmatrix} mm \\ mm \\ 1 \\ 1 \end{Bmatrix}, \qquad \boldsymbol{F} = \begin{Bmatrix} F_x \\ F_y \\ M_x \\ M_y \end{Bmatrix} \quad \text{unit} = \begin{Bmatrix} N \\ N \\ N-mm \\ N-mm \end{Bmatrix},$$

$$\boldsymbol{M} = \begin{bmatrix} N-s^2/mm & & & \\ & N-s^2/mm & & \\ & & N-mm-s^2 & \\ & & & N-mm-s^2 \end{bmatrix} \quad kg = N-s^2/m$$

$$\boldsymbol{C} = \begin{bmatrix} N-s/mm & & & \\ & N-s/mm & & \\ & & N-mm-s & \\ & & & N-mm-s \end{bmatrix}$$

$$\boldsymbol{K} = \begin{bmatrix} N/mm & & & \\ & N/mm & & \\ & & N-mm & \\ & & & N-mm \end{bmatrix}$$

To convert mass kg : $N-s^2/_{mm} = grams = 10^{-3} \times kg$

To convert Inertia kg-m^2: $N-s^2-mm = 10^3 \times kg-m^2$

To convert density: $N-s^2/_{mm^4} = g/_{mm^3} = 10^{-12} \times kg/_{m^3}$

To convert unbalance: $N-s^2 = 10^{-3} \times kg-mm$

To convert viscosity: $N-s/_{mm^2} = 10^{-9} \times centipoise$