Chain Analysis Using VALDYN

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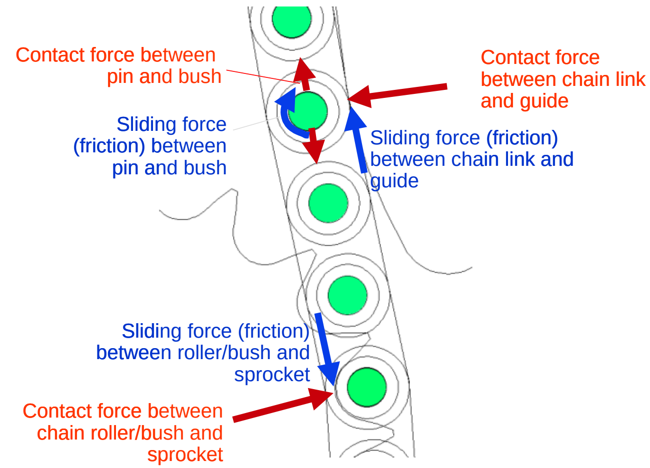
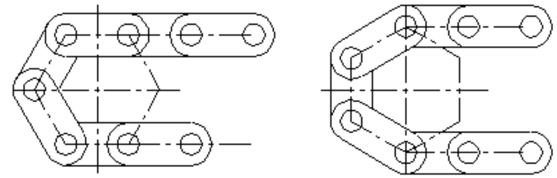
Contents

Timing Drive Analysis
Overview

- Multiple valvetrain models can be joined together to form a complete camshaft
  - Valve timing (phasing) can be modified simply
- Camshaft can be modelled in two ways
  - 1-dimensional. Torsional motion/stiffness of camshaft modelled
    - Usually used for timing drive analysis with simple camshaft arrangement
  - 3-dimensional. Bending, axial and torsional vibration included (all 6 degrees of freedom modelled)
    - Can be modelled using discreet 3D shaft elements OR by importing FE model of camshaft
- VALDYN has the capability to model the following chain types and has a simple user interface
  - Roller / Bush chain
  - Silent chain
  - Other special chains with novel designs



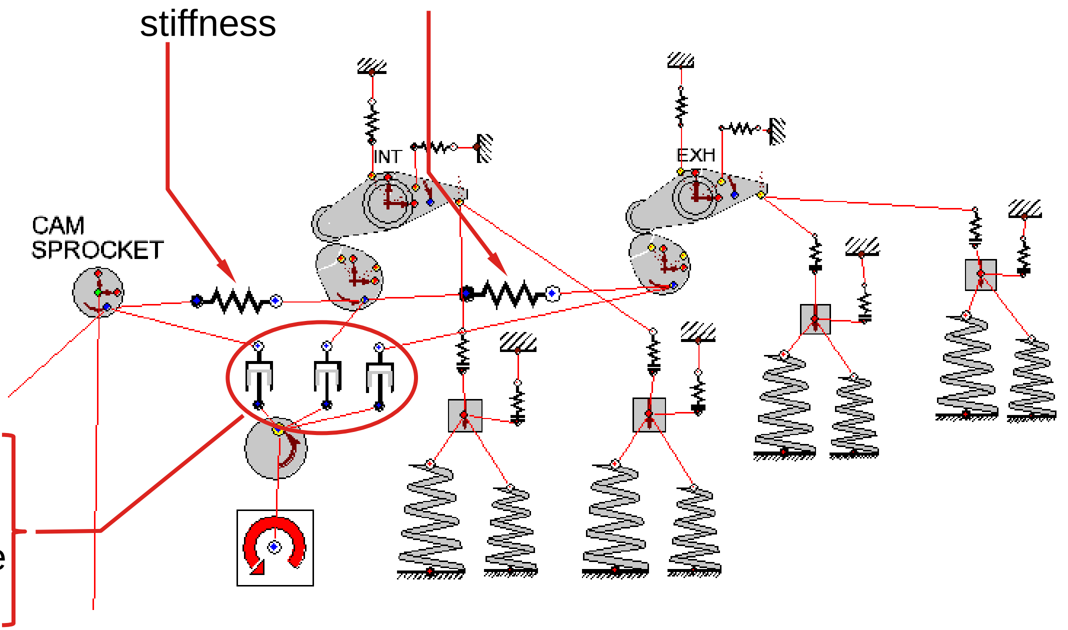
- Each chain link is modelled as a separate mass
  - Connected to adjacent links by stiffness
  - Connected to sprockets and guides by contact stiffness elements
- The detailed geometry of the chain, sprockets and guides is modelled accurately with effects of polygon action and lateral chain vibration are captured



Timing Drive Modelling – Assembly Camshaft

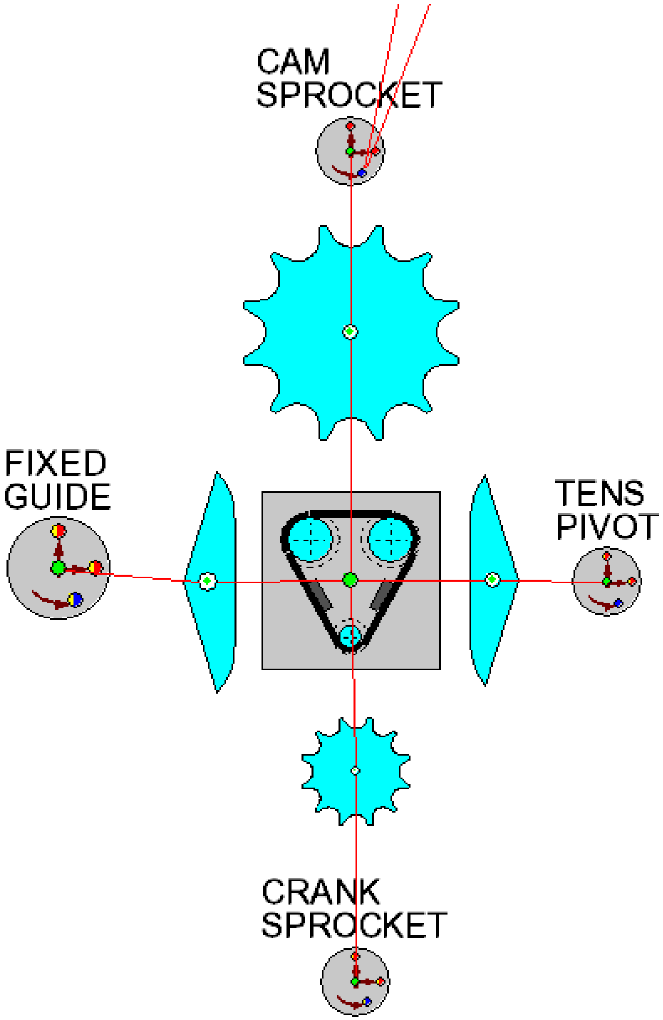
- Copies of the valvetrain model can be made for each valve train assembly
  - Valve profiles must be correctly phased
  - Or multi-cylinder engine the Initial conditions for each valve assembly should be set to improve speed of convergence
  - HLA elements representing valve hydraulic lash adjusters or hydraulic chain tensioners can be activated after a specified delay period to prevent the element pumping up during initial transients
- Cam rotational nodes are connected torsionally with a stiffness representing the torsional stiffness of the camshaft sections
  - Damping in the stiffness elements is set to ~0.2% critical based on the 1st camshaft torsional mode
- Each cam NODE is connected to a NODE rotating at camshaft speed with a DAMPING element to represent damping from the camshaft bearings
  - Typical bearing damping is 0.02 N.m.s/rad per bearing
  - The damping can be split proportionally across the camshaft masses
- Initial velocities of all camshaft rotational nodes should be set to 0.5 rad/rad

Camshaft torsional stiffness



Timing Drive Modelling – Assembly Layout

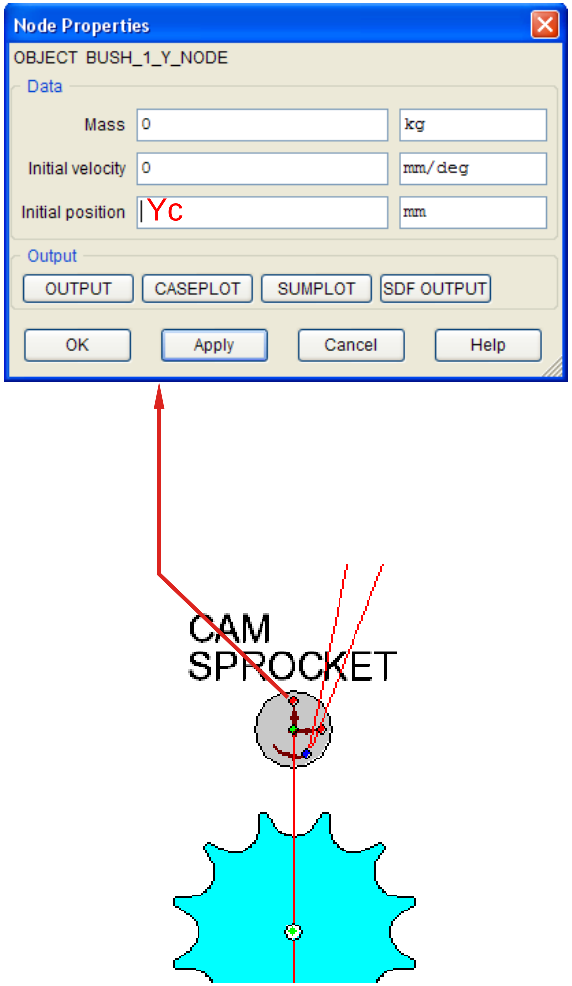
- Set out the layout of the GUIDE and SPROCKET elements around the CHAIN_V2 element and attach each GUIDE and SPROCKET element to a BUSH element as shown

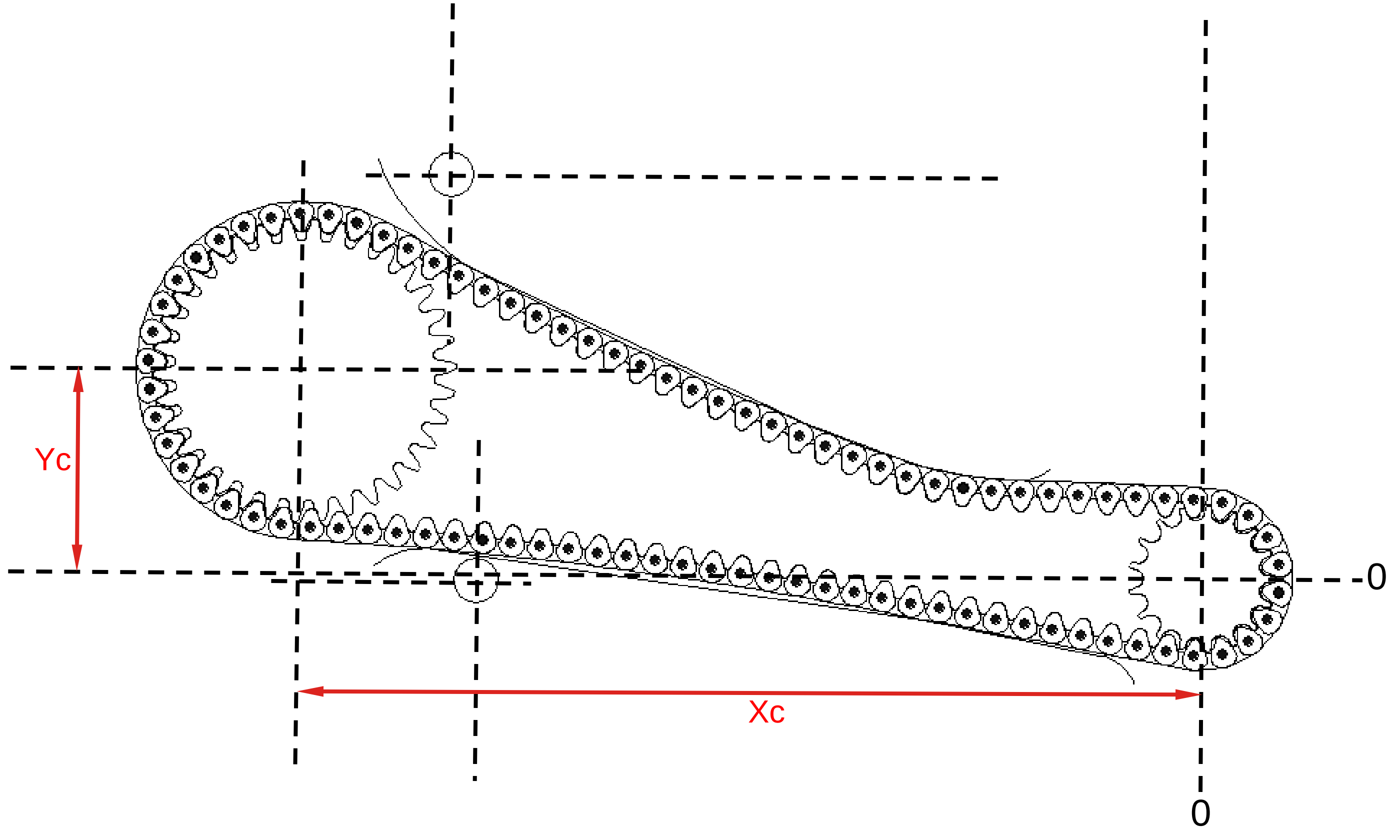


- The CHAIN_V2 element contains data which defined the chain properties and geometry and controls the wrapping of the chain around the attached SPROCKET and GUIDE elements
- The SPROCKET and GUIDE elements define their respective geometry and contact properties for interaction with the chain
- The chain, sprocket and guide geometries are all defined by LAMINAGEOM elements referenced within the respective element
- The MASS elements attached to the SPROCKET and GUIDE elements define the position and mass properties of the component

Timing Drive Modelling – Assembly Layout

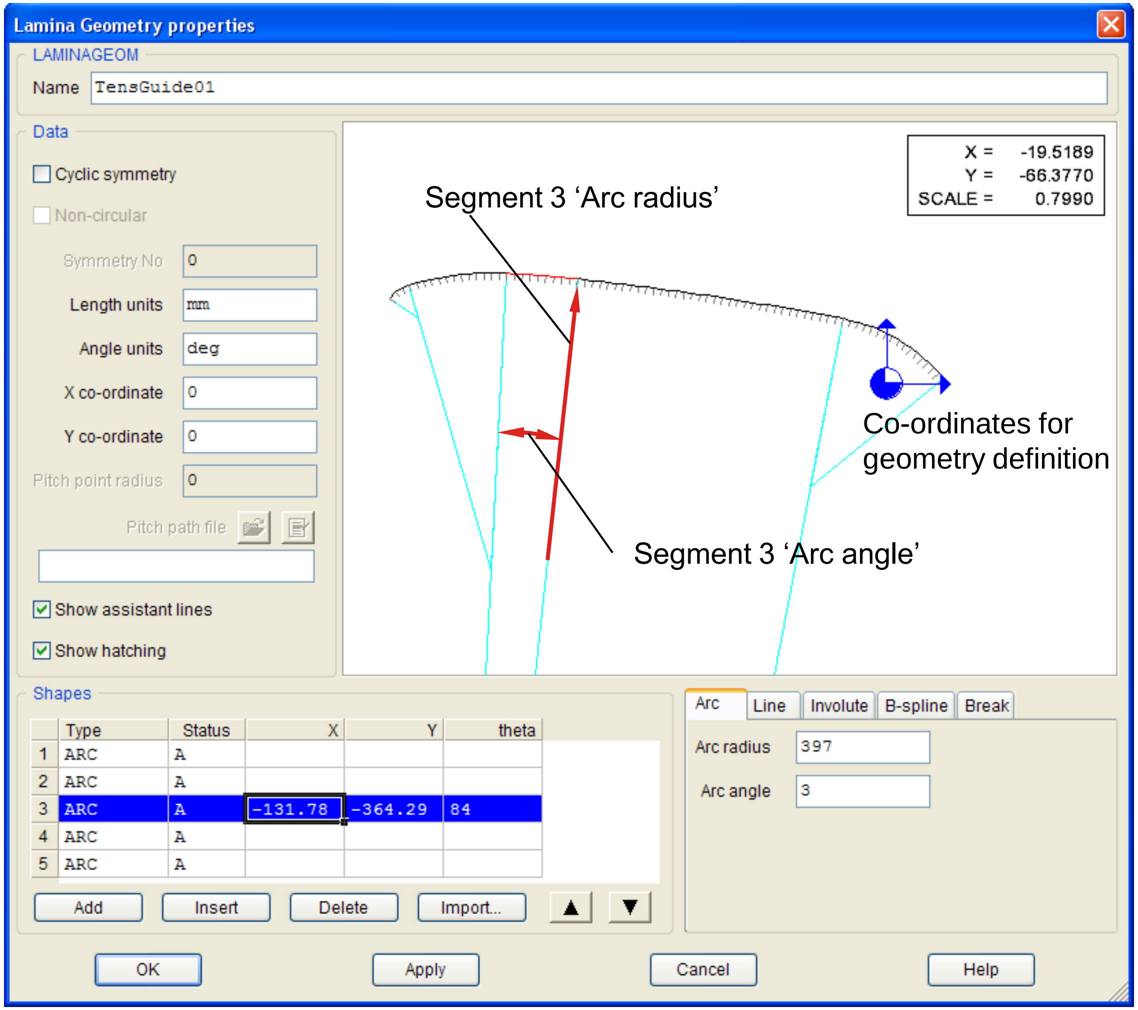
- Set the positions of the BUSH elements to define the sprocket and guide positions as determined by a layout drawing of the timing drive



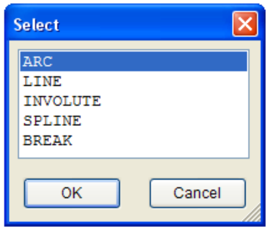


Timing Drive Modelling – Assembly Guide – Geometry

- Define the geometry of the guides as determined by a CAD model or 2D drawing of the guide components
  - Under the ‘Guide Shape’ group click ‘Add’ to bring up a new LANINAGEOM planel (shown)



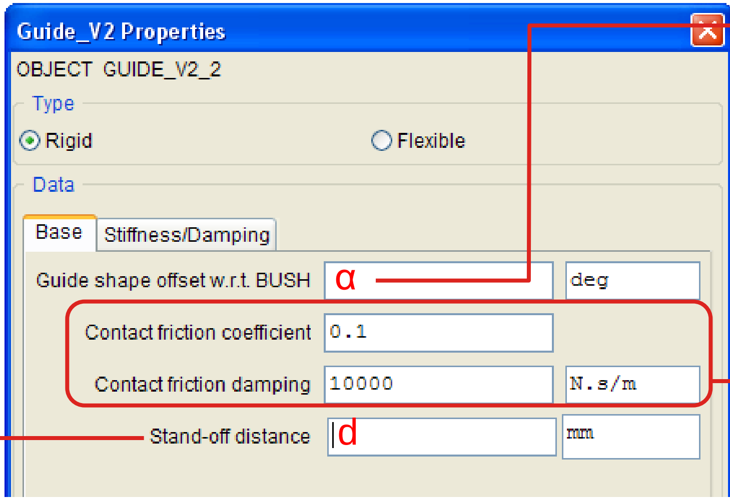
- The co-ordinate system of the 2D component drawing is likely to be different from the co-ordinate system for the timing drive layout, however the geometry can be rotational transformation can be specified to deal with this (See next slide)
- The segments must be defined in an anti-clockwise order to ensure the solid side of the profile is correct (shown by hatching)
- For each segment click ‘Add’ or ‘Insert’ and select the required segment type to create a new segment definition



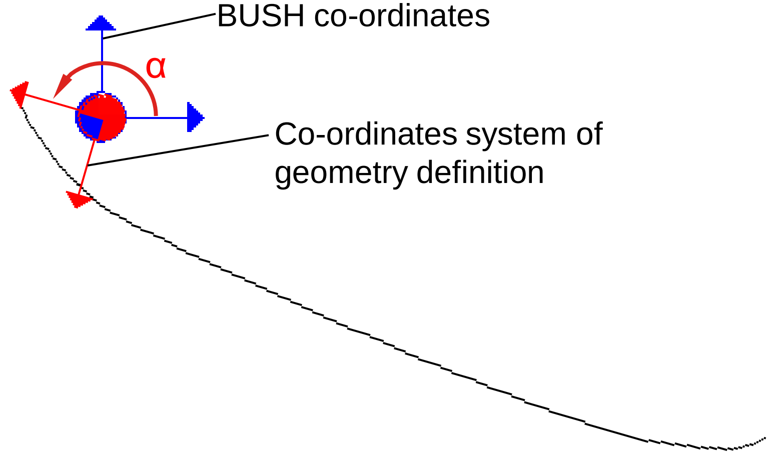
- The geometry can be broken into multiple series of segments
- X, Y and Theta specify the origin and orientation of a segment - required only for one segment in each (unbroken) series
  - For the guide shown the geometry is positioned based on segment 3

Timing Drive Modelling – Assembly Guide – Properties

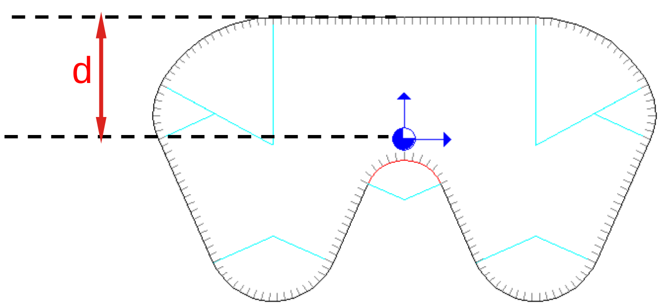
- Define the general properties of the guides



  - The Guide shape offset defines the angular orientation of the defined geometry relative to the BUSH element



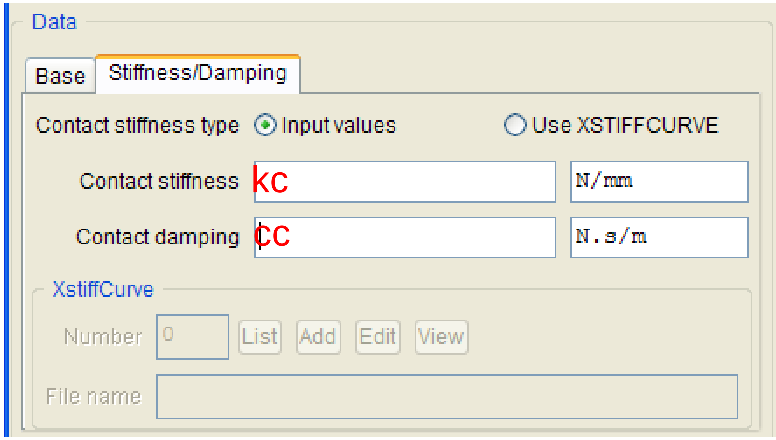
  - The stand-off distance is used only when wrapping the chain to define the distance between the face of the guide and the centre of the chain link



  - Link to guide contact friction properties (See Friction Properties section)
    - Typical values are < 0.1 but will vary across the speed range and operating conditions

Timing Drive Modelling – Assembly Guide – Properties

- Define the contact properties of the guides



– The dynamic results are usually not greatly sensitive to the chain to guide contact stiffness and can usually be set to a typical value of ~10000 N/mm

– A contact stiffness can be estimated based on the chain and guide materials

- The effective contact stiffness will be lower than that calculated due to the base compliance of the guide
- Contact damping is set to ~25% critical based on the link mass on the contact stiffness

Contact stiffness

$$kc := kf \cdot L \cdot \left[\frac{2 \cdot \left(1 - v_1^{2}\right)}{\pi E_1} + \frac{2 \cdot \left(1 - v_2^{2}\right)}{\pi E_2} \right]^{-1} \quad \text{(kc)}$$

Damping coefficient

$$cc := 2(25\%) \cdot \sqrt{mc \cdot kc} \quad \text{(cc)}$$

L = Contact length (total width of contacting links)

E_L, v_L, E_G, v_G = Elastic modulus and poisson ratio of link and guide respectively

mc = contacting mass (average of odd and even link mass)

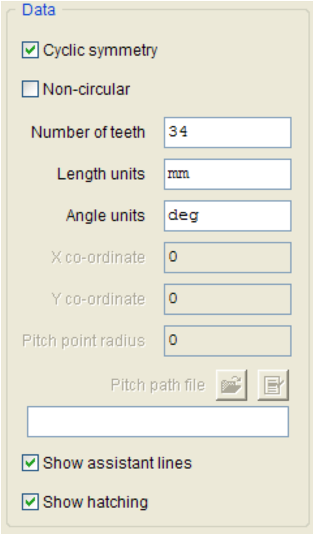
kf = effective stiffness modification (< 1), depending on guide support / materials

Timing Drive Modelling – Assembly
Sprocket Geometry

- Sprocket geometry should be obtained from the chain supplier
- The sprocket geometry may be defined by a combination of segments which can include
  - Splines fitted to X-Y data
  - Involute profiles
  - A series of simple arcs and lines
- The following slides show the definition of a 34 Tooth cam sprocket for a 6.35 mm pitch silent chain by specification of Involute geometry

Timing Drive Modelling – Assembly Sprocket Geometry

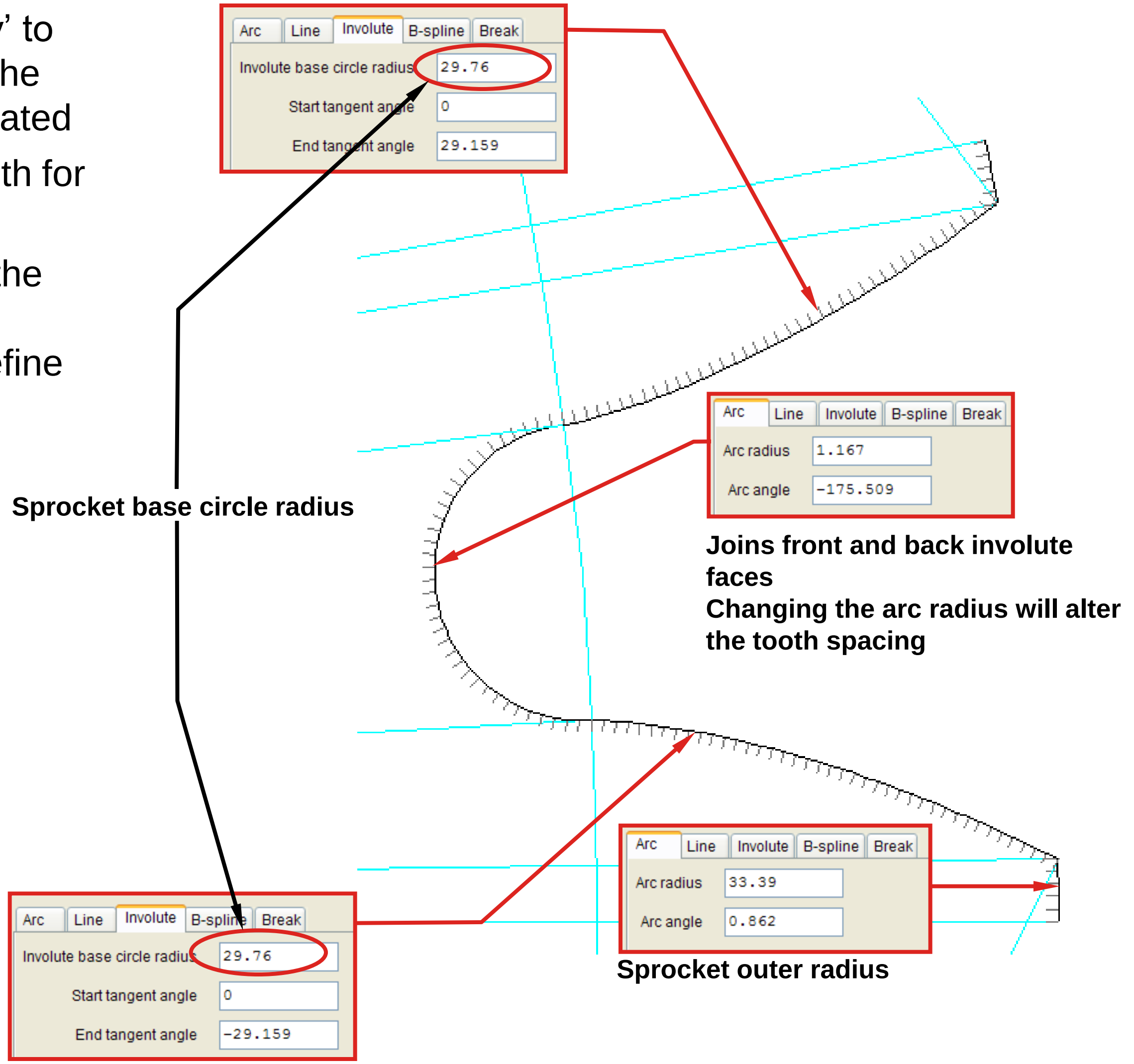
- Definition by Involute profile geometry



  - Select ‘Cyclic symmetry’ to show the geometry for the single tooth will be repeated
  - Enter the number of teeth for the sprocket
  - The geometry defining the single tooth will be repeatedly rotated to define the entire sprocket

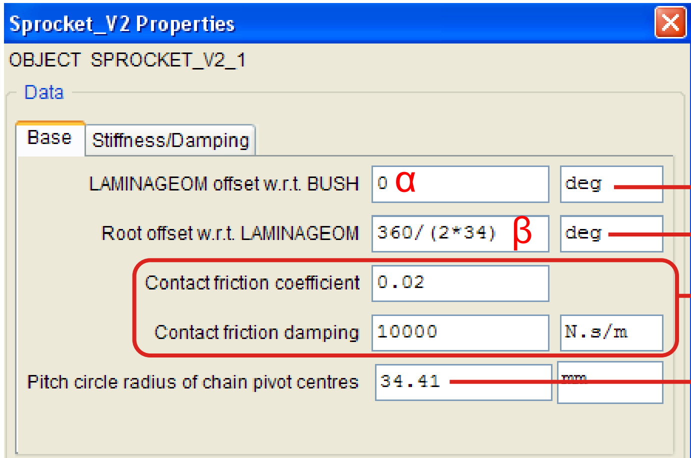
Shapes

	Type	Status	X	Y	theta
1	ARC	A	0	0	0
2	INVOLUTE	A	0	0	3.049
3	ARC	A			
4	INVOLUTE	A			
5	ARC	A	0	0	9.726

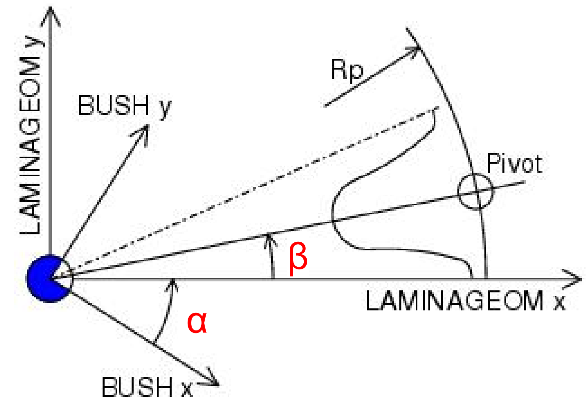


Timing Drive Modelling – Assembly
Sprocket Properties

- Define the general and contact properties of the sprockets



  - The sprocket geometry rotational offset with respect to the bush is used to control the start of the chain wrap (see Chain Wrap section)
  - Angular position of the tooth root in the LAMINAGEOM co-ordinate system (see right)

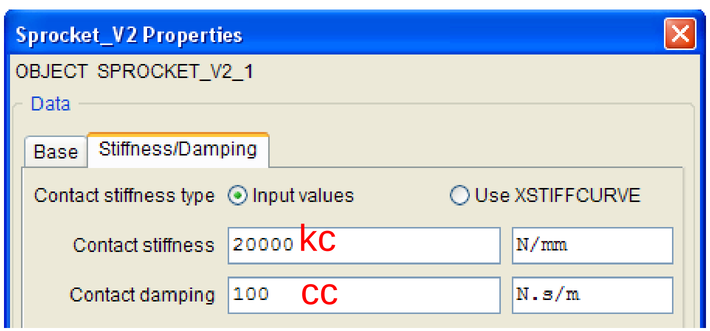


  - Chain to sprocket contact friction properties (See Friction Properties section)
  - The pitch circle radius is used when wrapping the chain to define the radial position of the pivot point

Pivot PCR

$$PCR := \frac{0.5 \cdot p}{\sin\left(\frac{\pi}{n}\right)}$$

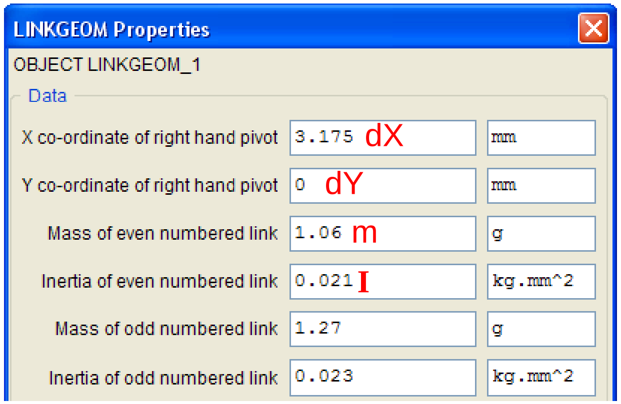
p = Chain pitch (6.35 mm)



  - The dynamic results are usually not greatly sensitive to the chain to guide contact stiffness and can usually be set to a typical value of ~20000 N/mm
    - Contact damping is set to ~25% critical based on the link mass on the contact stiffness

Timing Drive Modelling – Assembly
Chain Geometry

- Define the chain link geometry and mass properties

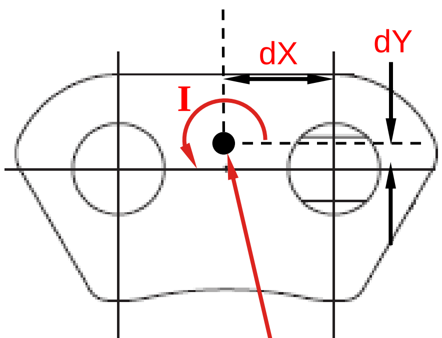


LINKGEOM Properties

OBJECT LINKGEOM_1

Data

X co-ordinate of right hand pivot	3.175 dX	mm
Y co-ordinate of right hand pivot	0 dY	mm
Mass of even numbered link	1.06 m	g
Inertia of even numbered link	0.021 I	kg.mm^2
Mass of odd numbered link	1.27	g
Inertia of odd numbered link	0.023	kg.mm^2



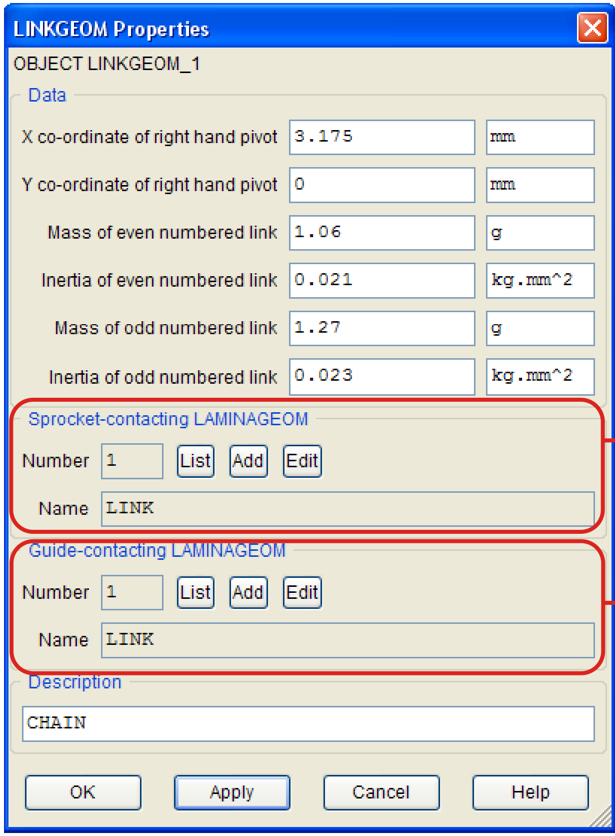
m (The BUSH which defines the link is at the c of g of the link assembly)

– Due to the construction of the chain the mass and inertia of the odd and even numbered links are different
  - For a 4x5 silent chain every odd and even link will have 4 and 5 plates respectively
  - The 2 outer plates of the 5 plate link will also be guide plates and therefore different to the other link plates
  - The pins are press fitted into the guide plates and therefore the mass properties of the pins must also be included along with the 5 plate link

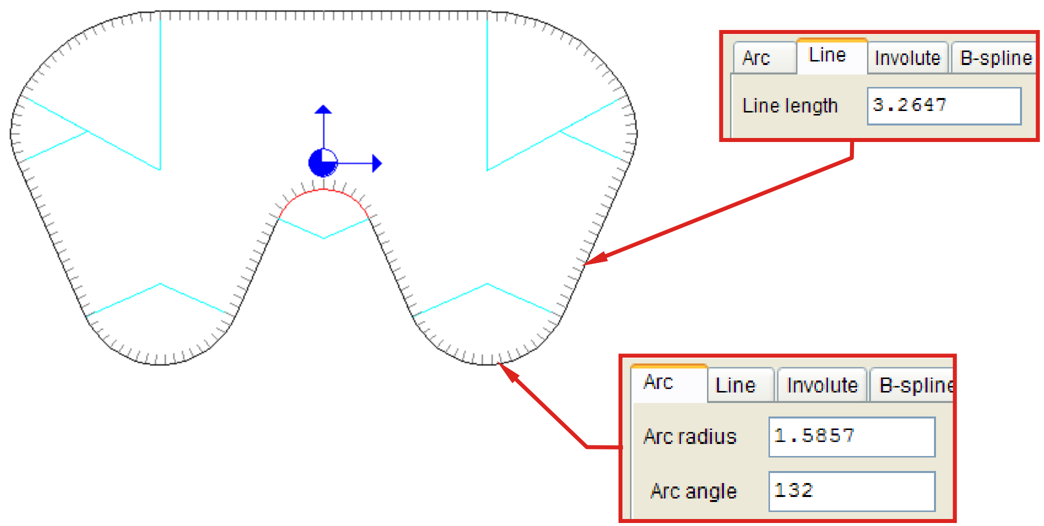
– For a 4x5 chain
  - Each odd link consists of 4 x link plate
  - Each even link consists of 3 x link plate + 2 x guide plate + 2 x pin

Timing Drive Modelling – Assembly
Chain Geometry

- Define the chain link geometry



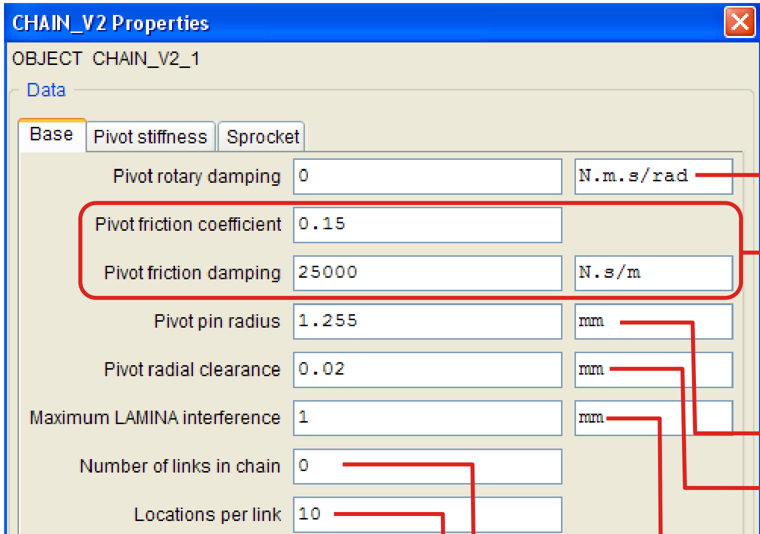
  - Click ‘Add’ to create a new LAMINAGEOM under the ‘Sprocket-contacting’ group and define the chain link plate geometry using the same method as with previous LAMINAGEOM



  - For a silent chain the link teeth contact the sprockets and the link back contact the guides
  - The same link geometry can therefore be used for both the ‘Sprocket-contacting’ and ‘Guide-contacting’ geometries
    - Click ‘List’ under the ‘Guide-contacting’ group to list the currently defined LAMINAGEOM elements and select the link geometry just defined

Timing Drive Modelling – Assembly
Chain Properties

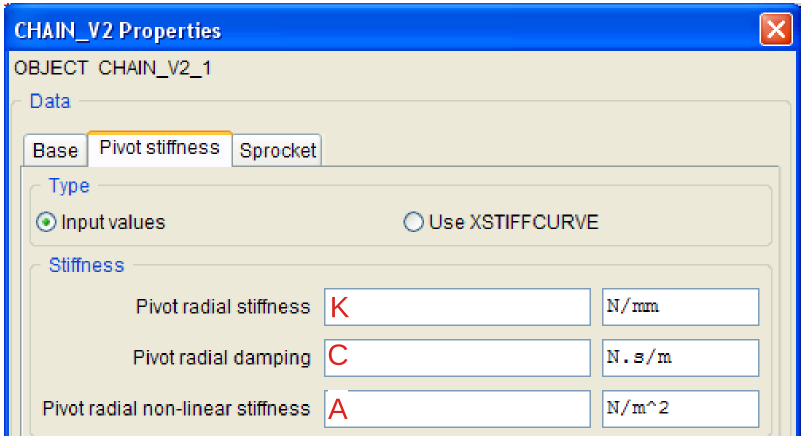
- Define the chain base properties

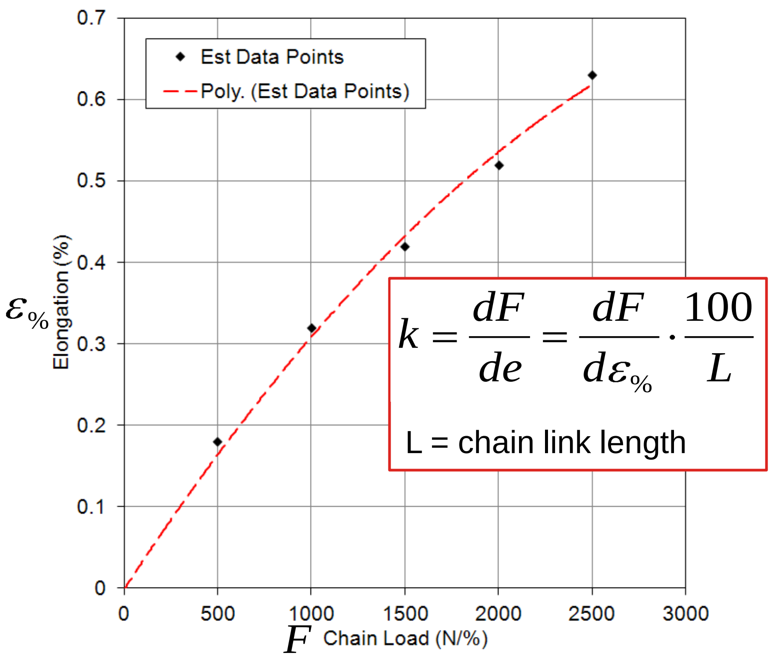


– Pivot rotary damping defines rotational damping at the chain link pivots
  - This can be set to improve correlation to measured vibration data
  - For investigations of friction losses this should be considered along with the friction properties as both will contribute to the total timing drive losses
– Chain pivot friction properties (See Friction Properties section)
– Pivot pin radius should be obtained from the chain data
– Pivot pin radial clearance will increase with chain life as the chain wears
  - 0.02 is typical initial clearance for pin size shown
– Maximum LAMINA interference defines the maximum allowable penetration of the contacting geometries and should be set to around half the radius of the smallest contacting arc
– Number of links can be set to a known number or set to zero so VALDYN calculate the number needed to form the chain run
– Locations per link defined the resolution of location based outputs (10 is usually adequate)

Timing Drive Modelling – Assembly
Chain Properties

- Define the chain stiffness properties





– The chain pivot stiffness defines the tensile stiffness of a single chain link and should be obtained from the chain supplier or from measurement

– The stiffness may be defined in two ways

- ‘Input values’ allowing specification of constant or linear increasing stiffness

$$F = K.e + A.e^2 + C\left(\frac{de}{dt}\right)$$

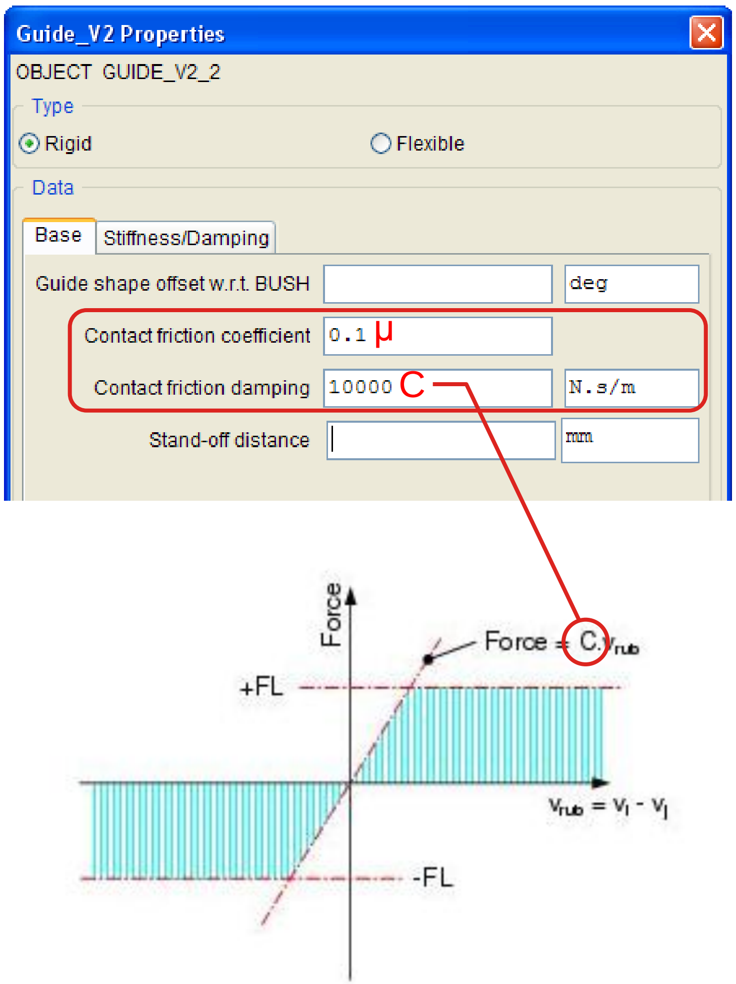
e = chain link extension
F = chain link load

- XSTIFFCURVE specifying a data file with 3 columns
  1: Extension (of link)
  2: Force (in link at corresponding extension)
  3: Damping (at extension)

– Measured force-extension data can therefore be used directly using the XSTIFFCURVE or by fitting a linear or quadratic polynomial to the data to obtain the stiffness coefficients K and A

Timing Drive Modelling – Assembly
Friction Properties

- Friction properties are required in the GUIDE, SPROCKET and CHAIN elements to define the chain-guide, chain-sprocket and chain pivot friction (Example for GUIDE element shown below)

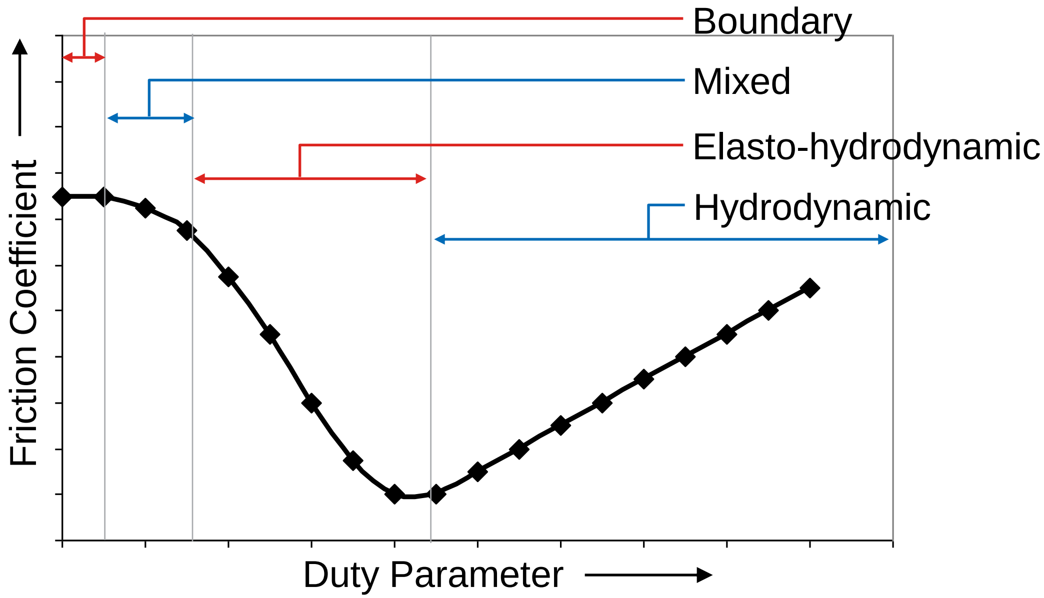


– The friction coefficient define the normal sliding friction coefficient at the respective interface
  - Typical values are < 0.1 - 0.2 but will vary across the speed range and operating conditions (see next slide)
  - The friction does not usually significantly affect the dynamic behaviour but is used for correlation and prediction of losses within the timing drive

– VALDYN currently uses a simple friction model with the contact friction damping being specified for numerical stability when the sliding velocity is close to zero

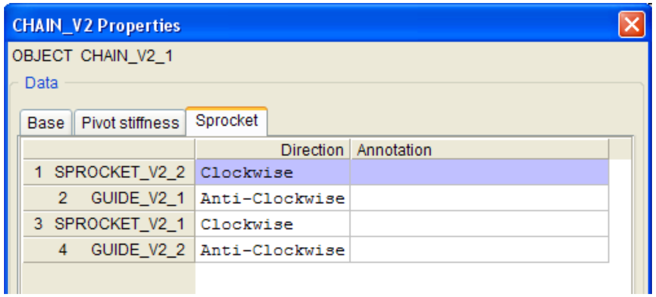
Timing Drive Modelling – Assembly Friction Properties

- The actual mechanism for the losses at the contacting interfaces of the chain will be a combination of boundary loss from asperity contact and hydrodynamic loss due to the presence of oil
- In VALDYN the detail of these interfaces are not calculated to this level but are represented by a specified friction coefficient
- The effective friction coefficient at each interface will depend on a local duty parameter, and will be some function of
  - Loading
  - Relative velocity
  - Oil viscosity
- The duty parameter will increase with increased velocity and/or increased viscosity and/or reduced load
- The function will also depend on
  - geometry and material of the contacting surfaces
  - surface roughness
  - magnitude and nature of the variation of load and velocity with time
  - availability and retention of oil at the interface
- In general the form of the variation of friction coefficient with a duty parameter is shown by the basic stribeck curve shown



Timing Drive Modelling – Assembly
Chain Wrap

- With the geometry and guide and sprocket positions defined the chain wrap can be checked
  - Under the ‘Sprocket’ tab of the CHAIN_V2 element the order and direction of the chain wrapping is specified
    - The crank sprocket should be first and it is recommended to wrap the chain in the opposite direction to the crank sprocket rotation
  - Run the simulation with the ‘Angle to start output’ and ‘Max angle to simulate’ set to zero causing VALDYN to calculate the chain wrap
    - The chain run can then be viewed in the animator
    - The discrepancy between the chain length and the chain run is output to the screen – the tensioner guide should be positioned to minimise this discrepancy

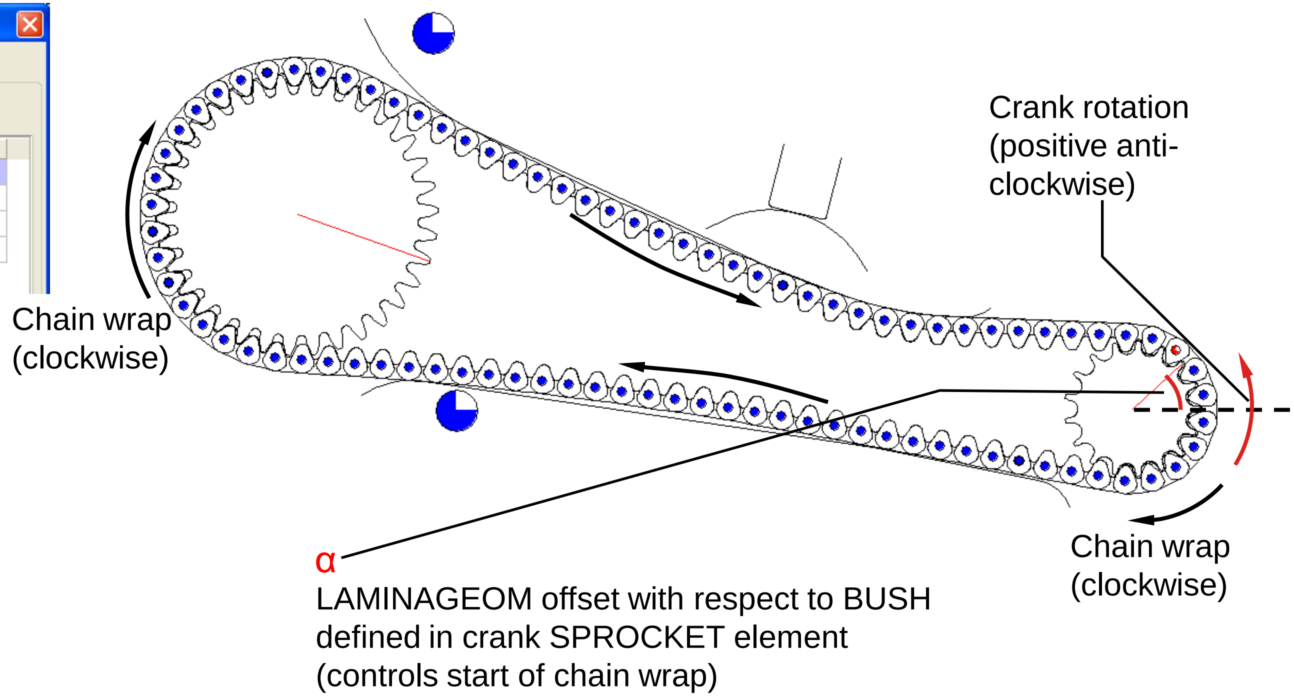

CHAIN_V2 Properties

OBJECT CHAIN_V2_1

Data

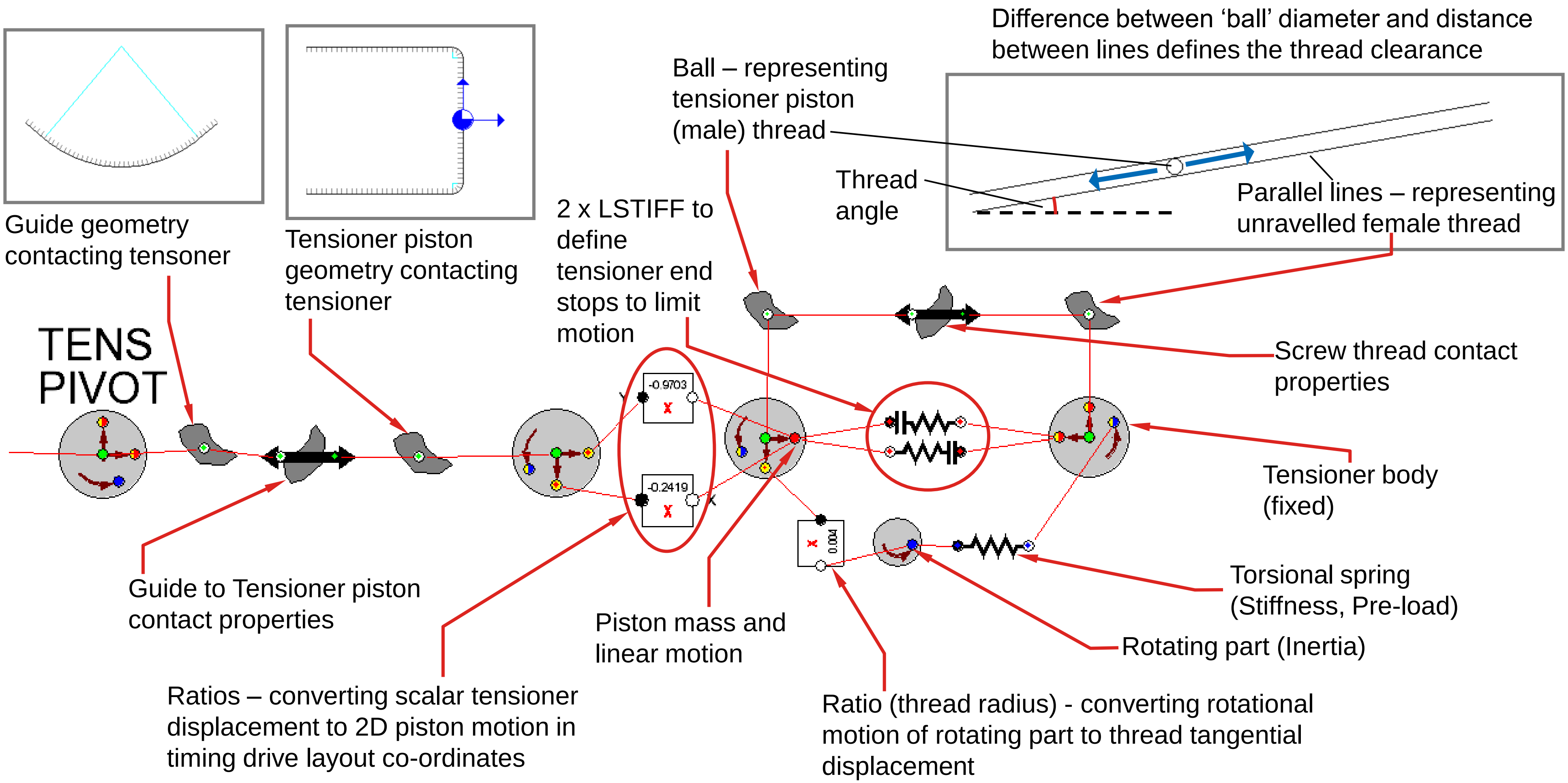
Base | Pivot stiffness | Sprocket

		Direction	Annotation
1	SPROCKET_V2_2	Clockwise	
2	GUIDE_V2_1	Anti-Clockwise	
3	SPROCKET_V2_1	Clockwise	
4	GUIDE_V2_2	Anti-Clockwise	



Timing Drive Modelling – Assembly Tensioner

- VALDYN can model hydraulic and ratchet tensioners using the HLA_V2 and RSTTIFF elements respectively
- The components required to construct a screw type tensioner are detailed below



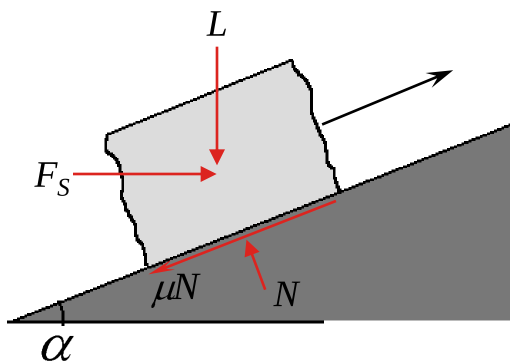
Timing Drive Modelling – Assembly Tensioner

- VALDYN can model hydraulic and ratchet tensioners using the HLA_V2 and RSTTIFF elements respectively
- The screw type tensioner operates on the following basis
  - A torsional spring acts between the tensioner body (A) and a female threaded component (B) which is free to rotate but constrained from linear translation
  - The tensioner piston is connected to the male threaded component (C) and constrained from rotating
  - The spring acts to turn part (B) causing the piston (C) to extend and loads on the tensioner piston cause part (B) to rotate against the spring and the piston to retract
  - The nature of the mechanism means the piston extends more easily than it can retract with the operation sensitive to the thread angle and the friction in the threads

Timing Drive Modelling – Assembly Tensioner

- Characteristics of screw adjuster tensioner

  - Extending (with friction)



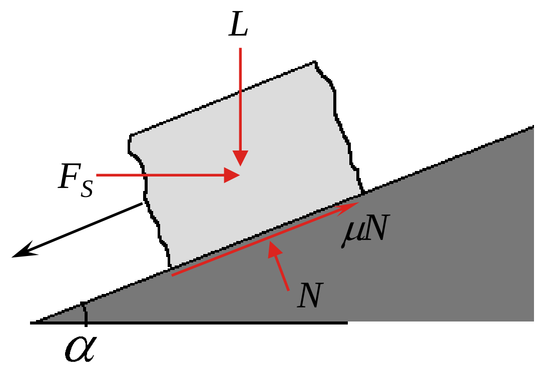
$$L = F_S\left(\frac{\cos\alpha - \mu\sin\alpha}{\mu\cos\alpha + \sin\alpha}\right)$$

  - The device will lock up when L = 0 for $F_S > 0$

$$\therefore \mu_{lock} = \frac{1}{\tan\alpha}$$

  - For $\alpha = 10\,\text{deg}$, $\mu_{lock} = 5.67$
  - For $\mu = 0.1$, $L = 3.6F_S$

  - Retracting (with friction)



$$L = F_S\left(\frac{\cos\alpha + \mu\sin\alpha}{\sin\alpha - \mu\cos\alpha}\right)$$

  - The device will lock up when $F_S = 0$ for L > 0

$$\therefore \mu_{lock} = \tan\alpha$$

  - For $\alpha = 10\,\text{deg}$, $\mu_{lock} = 0.18$
  - For $\mu = 0.1$, $L = 13.3F_S$

  - No friction

$$\mu = 0$$

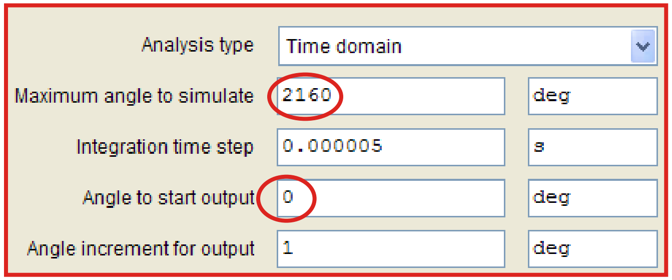
$$L = F_S\left(\frac{1}{\tan\alpha}\right)$$

  - The device cannot lock
  - For $\alpha = 10\,\text{deg}$,

$$L = 5.7F_S$$

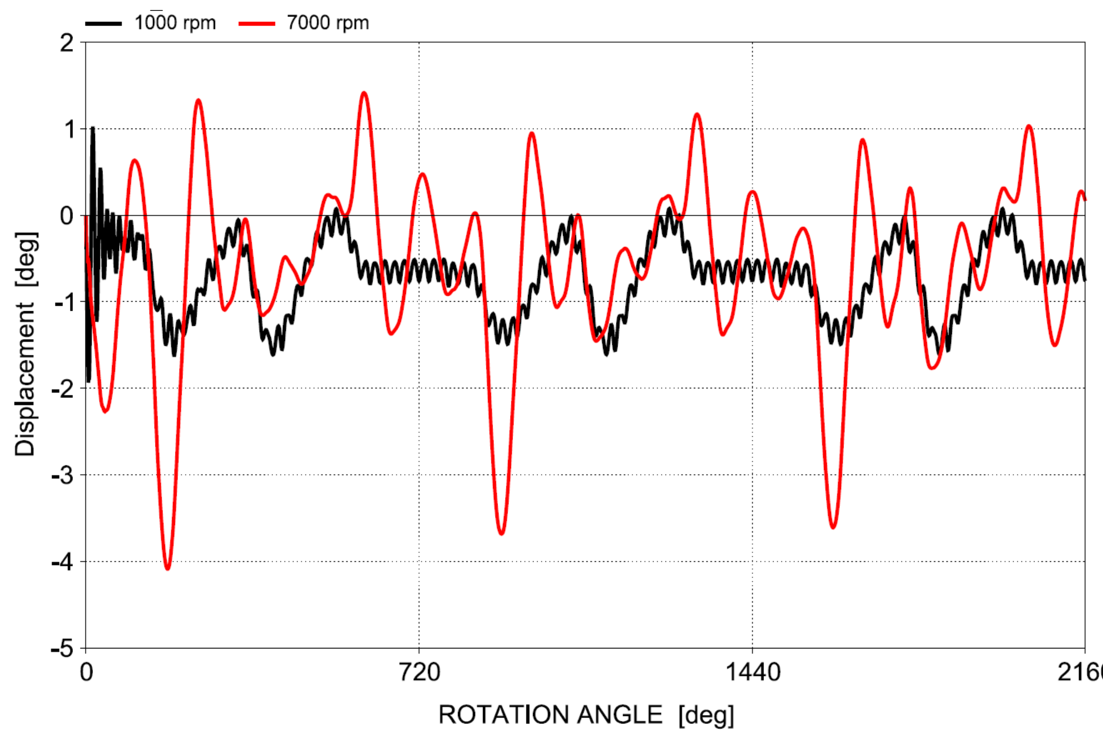
Timing Drive Modelling – Analysis Simulation & Results

- Before running a full simulation across the speed range the cycle to cycle convergence should be assessed to determine the number of cycles (therefore the maximum angle) to run the simulation for



  – To do this set the simulation to run for a number of cycles (~3 = 2160 deg) setting the ‘Angle to start output’ parameter to 0 deg (See left)
  – Run the simulation at the lowest and highest speeds only

- To assess the convergence check a typical case outputs over the output range (such as the cam to crank sprocket relative displacement) to check the cycle to cycle variation has settled (eg the last cycle is similar to the penultimate cycle)



Timing Drive Modelling
Simulation & Results

- The following result parameters can be used to judge the dynamic timing drive performance
  - Peak chain load
    - The peak chain load should be compared to limits supplied by the chain supplier for ultimate load and fatigue load
  - Minimum chain load
    - Generally the chain load should be prevented from reaching zero to avoid larger chain vibration and resulting greater peaks in chain load
  - Chain-Guide and Chain-Sprocket contact loads
  - Cam sprocket displacement
    - NVH
    - Parameter for correlation to measurements
  - Tensioner – guide contact load
    - The tensioner load should be minimised
  - Tensioner motion
  - Friction
    - For detailed assessment of losses