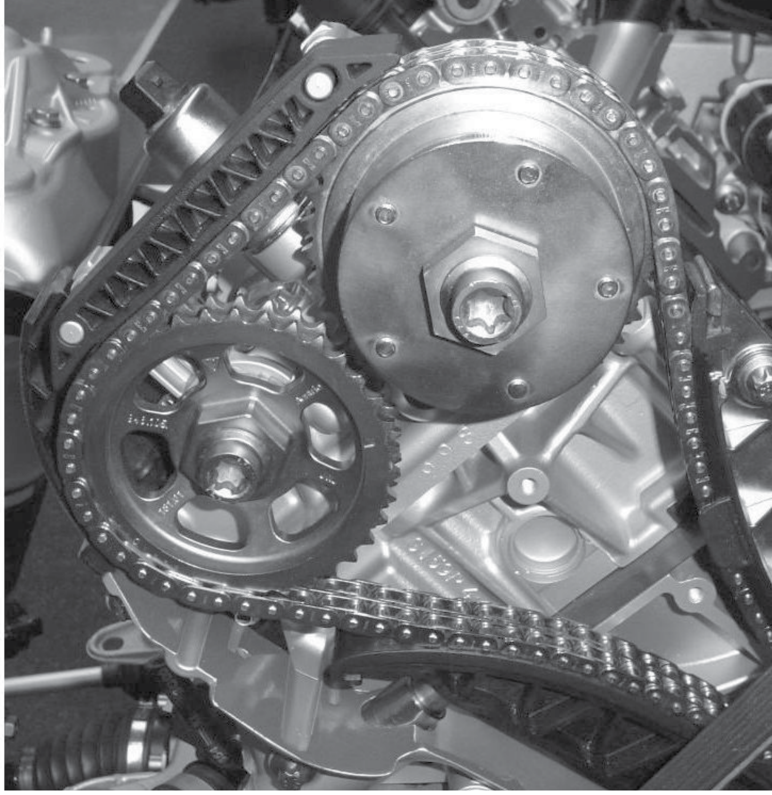

Design and Analysis of Chain Drives made easy by RecurDyn Multi-Body Software

RecurDyn is an emerging simulation technology to investigate both kinematics and dynamics of moving mechanisms. Despite being relatively young, RecurDyn is gaining significant portions of the Multi-Body-Simulation market by exploiting its unique features. In particular, the platform and its solver are optimized to efficiently manage virtual models characterized by high frequency dynamics and/or highly discontinuous phenomena. This is the typical scenario when the mechanism includes flexible bodies and/or contacts. Flexibilities bring into the model high frequency vibrations that combine with low frequency motions, whereas contacts add repetitive impulses that disturb the solution and excites vibrations.

Figure 1 – Polybolos reconstruction by the German engineer Erwin Schramm (1856–1935)

The power of RecurDyn's solver is really made available to the users through an intuitive GUI, that speeds up any pre-processing task that requires hand work. In addition, the platform includes a series of so called "toolkits" which automate the modelling of typical mechanical subsystems such as gears, belts, bearings, springs, chains, and more. Each toolkit creates bodies, joints, contacts and forces in accordance to the user inputs and, at the same time, adds special analytics for the system that is created.

Although RecurDyn can be used effectively in a unlimited number of situations, one of the applications where it really makes the difference is the simulation of chain drives. This short article presents the RecurDyn chain toolkit, which makes possible to model, simulate and analyze several types of standard chain transmissions. The customized interface of the toolkit guides the user through the necessary steps to assembly sprockets, links, guides, and tensioners. The internal library includes ISO standard components, so that even the CAD is automatically created. From this short introduction, the reader might argue that non-standard chains cannot be analyzed with RecurDyn. This would be a hasty conclusion. Indeed, RecurDyn features a programming environment, called PNet, through which the user can conveniently automate the operations that are needed to adjust the

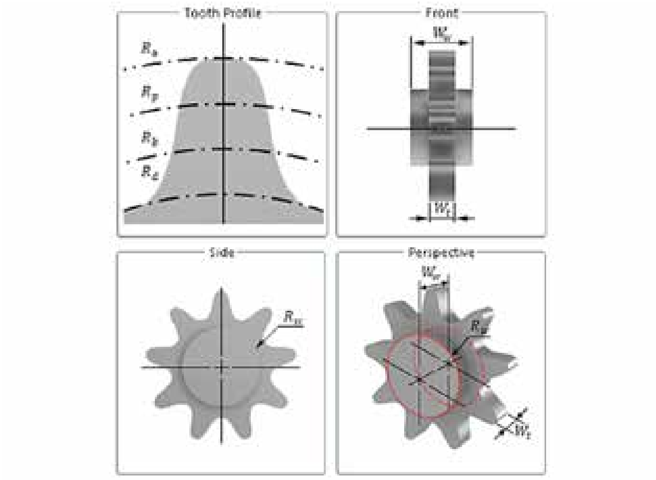

Figure 2 – Sprocket properties

model towards a fully customized chain.
Chain drives are mechanisms used to either transfer power from one location to another or to carry objects around. The first documented chain drive dates back to the 3rd century before Christ, and was used in a polybolos (Figure 1), which is a very ancient missile weapon. Chain drives have been improved a lot since then and cover a variety of application in any field of industry today. Besides being relatively cheap, they have a large power-to-weight ratio, they guarantee the position of the driven parts and can be used to cover a large range of distances. The use of chains is so diffused that is even difficult to select a main application as reference. In this article we will focus on the analysis of a simple timing chain, that is used to synchronize the camshaft rotation with the crankshaft rotation in internal combustion engines. This chain transmission has severe requirements such as precise positioning, low noise emission, large range of operating speeds, long time resistance, and so on.

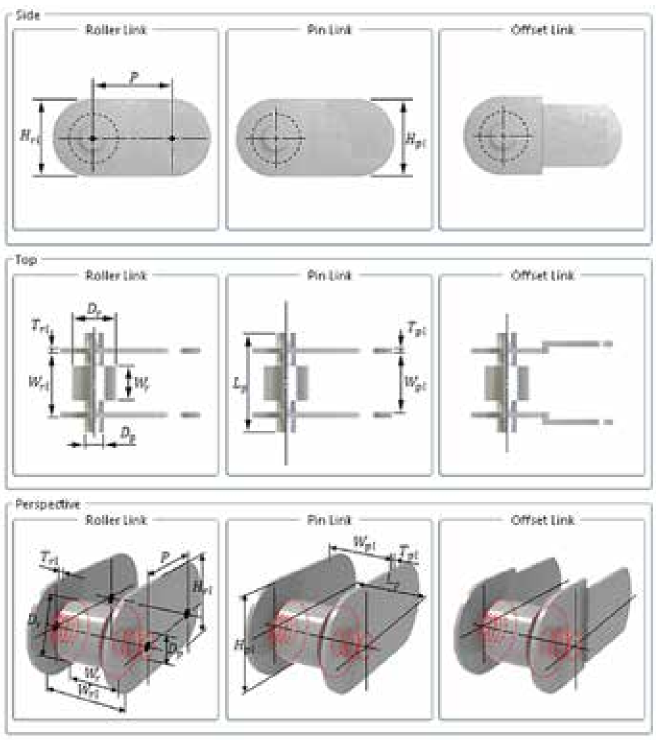

Figure 3 – Link geometrical properties (roller chain type)

Model creation through RecurDyn/Chain Toolkit

Once the Chain Toolkit is activated from the GUI, a set of specific icons appears in the menu bar. The toolkit is designed to model a chain drive composed of rigid bodies only. The CAD of these bodies is internally generated as the user inputs the necessary properties. The sprockets are the toothed gears that provide both input motion and any resistant torque in the chain drive system. Each sprocket requires the input data shown in Figure 2. The chain drive might also feature also some rollers, which are like pulleys that affect the chain direction without transferring any longitudinal force.

Once the rotating elements are all in place, then the user is requested to define the chain itself. This task is accomplished by first choosing from the menu the type of link. The user has to input the sizes of

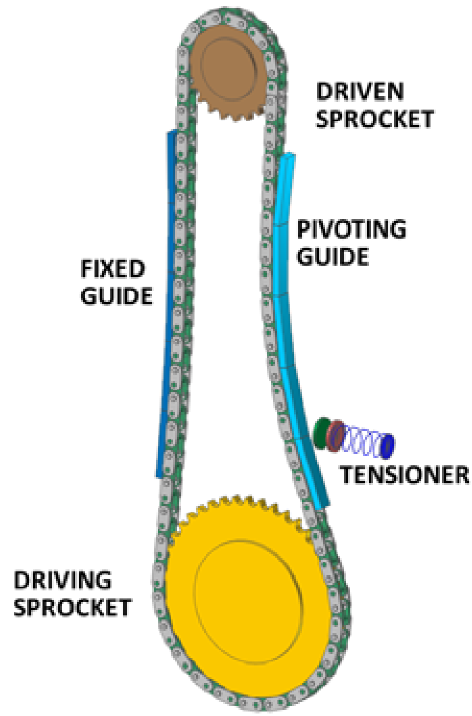

Figure 4 – Multi Body model of a timing chain

two links only, since the chain is just a series of them. RecurDyn makes possible the modelling of roller chains, multiplex chains, and silent chains. As an example, the Figure 3 shows the input data to completely define the links of a roller chain type.
The third crucial task, fully automated in RecurDyn, is the assembly of the chain. The user is requested to trace in sequence the straight branches of the chain path, by simply touching with the mouse the sprockets and the rollers that have been previously built. Once done with the path, the software replicates the links so that the chain completely covers the path. The resulting chain is fully connected and approximately engages the sprockets. In a timing chain the path is clearly closed (chain loop), but other applications might require an open path; RecurDyn can manage both.
Further components, which are very common in a chain drive system, are the guides and the tensioners. The guides are either curved or straight pads that prevents the chain from radial and/or lateral motion. Sometimes guides are not fixed to the chain bench and are coupled with a piston that provides a controlled force. This device is known

as tensioner and is really important to keep the desired level of longitudinal load as the chain elastically deforms or gets longer for wearing. A simple timing chain looks like the one shown in Figure 4. In this example both driving and driven sprockets are attached to the workbench through revolute joints. The driving joint is coupled to a rotational actuator, whose angular speed matches a time history measured in laboratory. The driven joint is coupled to a rotational actuator, whose resistant moment matches the torque signal measured in laboratory as well. Therefore, the boundary conditions for the chain system are reliably reconstructed. For a more detailed analysis, the timing chain model could be extended by adding the crankshaft, the valve shaft, and more components.
In this demonstrative and basic model, the tensioner force has been modeled as simple elastic reaction, represented with a spring icon in Figure 4. More generally, RecurDyn makes possible to define much more sophisticated models of this force, including hydraulics, non-linear friction, and non-linear springs. Moreover, the dynamic model can be connected to matlab Simulink or AMEsim, when more sophisticated models of the tensioner force are available in these platforms.

Chain Model Characteristics

The chain toolkit assemblies the model and automatically creates the contacts and the joints through which all parts interact together. Chain links are held together by bushing elements, which are 3-dimensional force elements. Each bushing applies 3 relative forces and 3 relative torques between the connected elements, which are calculated as functions of relative displacements, relative rotations, relative translational speeds, and relative rotational velocities. Stiffness and damping functions can be fully customized, so that any type of global response can be matched. As an example, by setting force and torque functions with a flat dead zone in the zero displacement range, it becomes possible to model the effects of gaps between the links. In general, the bushing properties must be calibrated to match the experimental response of known chains. It is worth to point out that deformable bushings at link-to-link connections make possible to describe the chain elasticity that, otherwise, would not be available with rigid bodies. The so modelled chain interacts with sprockets, guides and rollers via non-linear frictional contacts. RecurDyn internally recognizes the shapes of the contacting surfaces, so that there is no need for the user to select them manually. Contact parameters such as stiffness and damping need to be input by the user, in accordance to FE analyses or experimental measurements. Depending on the type of chain.

Simulation and Review of Results

Chain models are among the largest and most complex that can be simulated with multi-body technology. First, depending on the chain length, the number of moving bodies could become remarkable. Second, contacts disturb the solution all over the chain, causing continuous impulsive excitation of the mechanism. Third, chain links are bodies with reduced inertia, whose motion is driven by stiff contacts and stiff bushings. RecurDyn has built its reputation on chain application. The main reason is its hybrid solver, which uses an innovative approach with respect to its competitor. Even chain models featuring hundreds bodies and thousands contact points can be simulated in a reasonable time.
Once the simulation is accomplished successfully, RecurDyn offers the possibility to extract and post-process a bunch of output quantities. By default, the model returns both translational and rotational quantities of each part, such as position, speed and acceleration in space. Simulations of very long chains generate large output files that are difficult to handle. For this reason, the user can select in advance the links he is interested to investigate in detail. The RecurDyn model also outputs both forces and moments on each link-to-link connection, as well as the contact forces between chain and any other element it interacts with. Since the chain dynamics is quite discontinuous, time histories of selected output quantities might look rather meaningless (i.e. high frequency oscillations). That's why RecurDyn post-processor includes specific tools such as frequency filters and FFT, that really facilitate the user's comprehension. More deeper investigations can then be performed outside RecurDyn using the data that are easily exported in txt format.
RecurDyn, in combination with its Chain Toolkit, is really the software solution for the industries that design chains or systems including chains.

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