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# Dynamic Analysis and Simulation of a Roller Chain Drive System on RecurDyn

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**Abstract.** This paper is on the dynamic analysis and simulation of the roller chain drive systems, which are widely used in various high-speed, heavy-load and power transmission application. Presently, most studies were only focused on the analysis of the chain tight span, not the whole system. In this paper, a mathematical model is developed to calculate the dynamic response of the whole roller chain drive working with RecurDyn software. It presents the generalized recursion theory of the chain links in the model, with the initial condition and various tension. In this simulation model, the dynamics of any roller chain drive with two sprockets and two spans can be analyzed by the procedure. Finally, it provides velocity curves, displacement diagrams, accelerating curves and dynamic tension curves. This study provides an effective way for the dynamic analysis of all the chain drive system.

## Introduction

The chain drive systems possess the merit of gear and belt wheel transmissioncan, which can be widely found in conveying applications as an effective way of transmitting power[1]. In practice, the major problems of roller chain drives are the vibration and noise. The variation carries change of the tension in the links moving from the tight (slack) side to the slack (tight) side, which will affect the frequency and amplitude of the chain[2]. Thus, many studies on dynamics of the roller chain drive systems are carried out.

In the last two decades, the research concerning chains is substantial, while the dynamic analysis and simulation of a chain drive system is always a complex issue. Recently, researchers have turned to kinetic analytical methods as a means for chain-sprocket interaction and chain drive[3]. C-K Chen and F.Freudenstein attempted to predict a more exact kinematics of roller chain drives as a four-bar linkage[4]. With the RecurDyn software, the tank entity model in CGF was developed, satisfying the storage of physical data with high efficiency and the requirement of fast running performance[5]. Additionally, a detailed experimental study on dynamics of roller chain drives were performed, which showed the vibration response of the chain under different motion characteristic was measured and compared[6]. Besides, finite element techniques and numerical simulation software were used for predicting the meshing noise due to the impact of chain rollers against the sprockets of chain drives[7]. Presently, the development of computers has made it easy to numerically solve some of equations given by the chain drives' complicated mechanisms.

This analysis concerns the numerical simulation of a roller chain for the dynamic response based on RecurDyn software, which can roughly be divided into two different areas. It presented a numerical model and the nonlinear equations from using the generalized recursion theory. On the other hand, it carried numerical simulation for the theoretical results by RecurDyn software. Through the analysis of the dynamic characteristics such as the geometric locus, the velocity and acceleration curve and the force, over all the dynamics of a roller chain system can be obtained. The objective of this paper proves to be a novel way to the wear and tear of a chain drive system.

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## Theoretical Analysis

**Generalized Recursion Theory.** Itemized deduction recursive algorithm makes the results and computing more complicated, which can be avoided by turning the motion equations into the compact matrix [8]. The generalized recursion theory is to analyze the algorithm structure of spatial constraint equation of motion, and classify the calculating operation at the same recursive fashion.

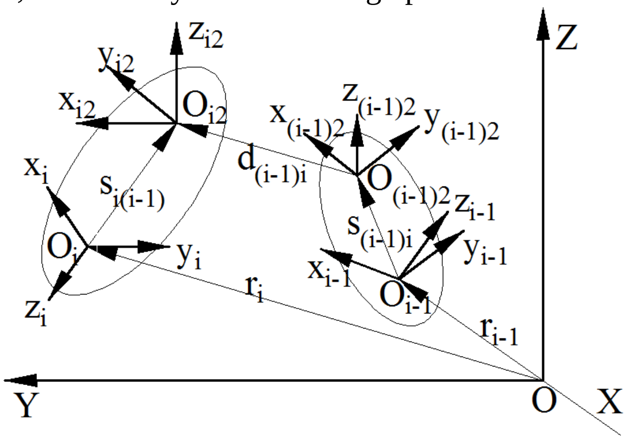


Fig.1 kinematic diagram between two adjacent parts

There is a pair of adjacent elements, in where the part(i-1) is the previous one of the part(i), as shown in fig. 1. And, the position of the point $O_i$ can be expressed as follows.

$$\mathrm{r}_i = r_{(i-1)} + d_{(i-1)i} - s_{i(i-1)} \tag{1}$$

In $A_{(i-1)i} = A^T_{(i-1)} A_i$, the rotational velocity of the part(i) in its own WCS can be got.

$$\omega_i = A^T_{(i-1)i}\,\omega_{i-1} + A^T_{(i-1)i} H_{(i-1)i}\,\dot{q}_{(i-1)i} \tag{2}$$

where $H$ is resolved by a slewing axis.

The derivation of the equation (1) is calculated as follows.

$$A_i \dot{r}_i = A_{(i-1)} \dot{r}_{(i-1)} - A_{(i-1)} \tilde{s}_{(i-1)i}\,\omega_{(i-1)} - A_{i-1} \tilde{d}_{(i-1)i}\,\omega_{(i-1)} + A_i \left(\tilde{d}_{(i-1)i}\right)_{q_{(i-1)i}} \dot{q}_{(i-1)i} \tag{3}$$

where the corresponding volume of the x-y-z WCS can be written as

$$Y = \begin{bmatrix} \dot{r} \\ \omega \end{bmatrix} = \begin{bmatrix} A^T_{\dot{r}} \\ A^T_{\omega} \end{bmatrix}$$

Meanwhile, the variables with the wave are the skew symmetric matrices from the vector cross product, and the $\mathrm{q}_{(i-1)i}$ is the relative coordinates vector.

$$\begin{aligned} \dot{\mathrm{r}}_i = {} & A^T_{(i-1)i} \dot{r}_{(i-1)} - A^T_{(i-1)i} (\tilde{s}_{(i-1)i} + \tilde{d}_{(i-1)i} - A_{(i-1)} \tilde{s}_{i(i-1)} A^T_{(i-1)i})\,\omega_{(i-1)} \\ & + A^T_{(i-1)i} ((\tilde{d}_{(i-1)i})_{q_{(i-1)}} + A_{(i-1)i} \tilde{s}_{(i-1)i} A^T_{(i-1)i} H_{(i-1)i})\,\dot{q}_{(i-1)i} \end{aligned} \tag{4}$$

where $\dot{A}_i = A_i \tilde{\omega}_i$.

a velocity recursive equation between the adjacent component pairs can be obtained in the equation (2) and equation (4).

$$Y_i = B_{(i-1)i1} Y_{(i-1)} + B_{(i-1)i2}\,\dot{q}_{(i-1)i} \tag{5}$$

where

$$B_{(i-1)i1}=\begin{bmatrix}A_{(i-1)i}^T & 0\\ 0 & A_{(i-1)i}^T\end{bmatrix}\begin{bmatrix}I & -(\tilde{s}_{(i-1)i}+\tilde{d}_{(i-1)i}-A_{(i-1)i}\tilde{s}_{(i-1)i}A_{(i-1)i}^T)\\ 0 & I\end{bmatrix}$$

$$B_{(i-1)i2}=\begin{bmatrix}A_{(i-1)i}^T & 0\\ 0 & A_{(i-1)i}^T\end{bmatrix}\begin{bmatrix}(\tilde{d}_{(i-1)i})_{q_{(i-1)i}}+A_{(i-1)i}\tilde{s}_{(i-1)i}A_{(i-1)i}^T H_{(i-1)i}\\ H_{(i-1)i}\end{bmatrix} \tag{6}$$

The matrices $B_{(i-1)i1}$ and $B_{(i-1)i2}$ are the relative coordinates functions only interrelated to the kinematic pair between the part(i) and part(i-1). From the derivation of $B_{(i-1)i1}$ and $B_{(i-1)i2}$ in the equation (6), all members of the equation are $0$ except the $q_{(i-1)i}$, which will immensely simplify the arithmetic procedure. Likewise, the recursive relation of the virtual displacement is as follows.

$$\delta Z_{\text{i}}=B_{(i-1)i1}\delta Z_{(i-1)}+B_{(i-1)i2}\delta q_{(i-1)i} \tag{7}$$

In this investigation, the recursive theory is used, from which the dynamic analysis of a roller chain system is very necessary.

## Dynamic Analysis and Simulation

### Problem Description

In RecurDyn software, the chain module contains sprocket wheels, chain links and the constraint condition, where the sprockets and chain can be auto-meshing as an assembly. And the library of chain links bring together all the standard norm. To reduce the transverse oscillation at the tight/slack span at higher speeds, which here is a reasonable chain structure. A roller chain drive system can be designed following the instruction of the chain subsystem in the chain library. For the numerical methods proposed in this article, a chain system with the transmission ratio $\text{i}=1:1$ is established, where the major parameters of the chain system are as shown in table 1 and table 2.

Tab. 1 Specifications of the sprockets

| *Parameter Name* | *Parameter Value* |
|---|---|
| Drive sprocket teeth | 21 |
| Driven sprocket teeth | 21 |
| Sprocket diameter | 213.025mm |
| Elastic coefficient | 10000 |
| Damping coefficient | 5 |
| Density | 7.85e-006kg/mm$^3$ |

Tab. 2 Specifications of the chain links

| *Parameter Name* | *Parameter Value* |
|---|---|
| Chain length | 1000mm |
| Chain number | ISO606:40A |
| Roller diameter | 19.850mm |
| Number of links | 53 |
| Chain pitch | 63.500mm |
| Density | 7.85e-006kg/mm$^3$ |

For the simplification of the operations, the specification of the drive sprocket is the same with the driven sprocket. At the same time, the driver function exerted in the drive sprocket is as follows.

$$\text{Step}(Time,0,0,1,10)*Time \tag{8}$$

That is to say, the initial condition of the drive sprocket is $0$, and then the velocity of the drive sprocket reaches to $10\text{mm}/s$ with which the chain system will be stirring.

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## Numerical Simulation Model

The chain drive consist of two sprockets, one driving and one driven, which connects the two sprockets through the tight/slack span, as shown in fig. 2. To reduce the transverse oscillation at the tight/slack span, the preload should be added by setting the parameter value of preload in RecurDyn software. The two sprockets must in some way be connected to the driving and driven mechanisms, in which the necessary parameters are introduced to mathematically describe the chain drive.

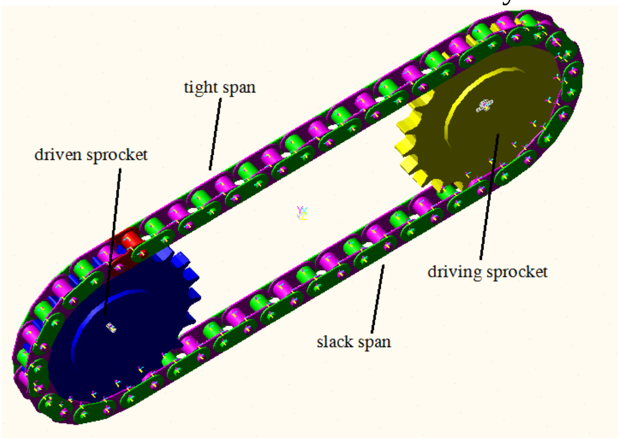


Fig.2 The chain drive model

The rollers in contact with the sprocket are able to move along the tooth flank. The position is given by the preload, the tooth surface geometry and the chain pitch. The geometry of the tooth flank given by the automatic generation in RecurDyn software defines the tooth flank as five pieces and is a mix of straight lines and arcs.

## Solving Procedure and Results

The simulation time is $5$ seconds with the step of $500$ in the simulation procedure. The moment of inertia for the two sprockets is set for meshing by rotating with low-angle. The model is solved until a steady state is achieved. Then, the dynamic curve can be got in the solving procedure.

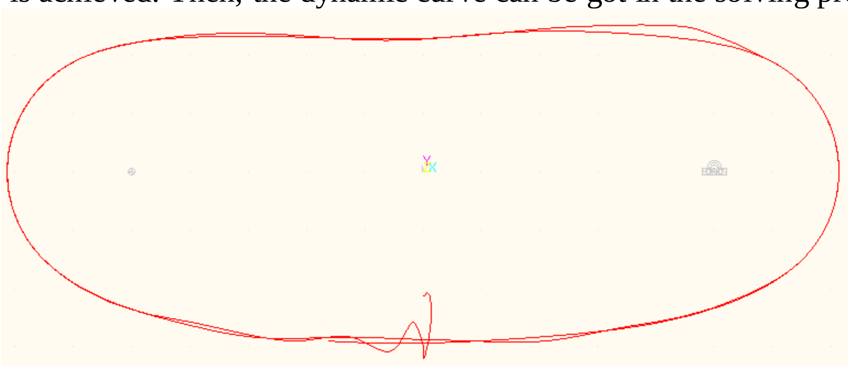

Fig.3 The trajectory of a chain link

Figure 3 shows the movement of a chain link in the chain drive system is not smooth, which is that there is a oscillation in the movement. So, more curves should be presented for analysis. The sprockets spin at the speed of $10 rad/s$ after the vibration at the beginning, however the rotational acceleration of the driven sprocket (sprocket 1) have severe vibration relative to the velocity, as shown in fig. 4. At the same time, the driving sprocket (sprocket 2) always operates steadily.

From the velocity and position curve of chain link 40 in fig. 5, the flow problem of the chain drive system is very obvious in the course of transmission, especially at the beginning. The position of the centre of mass in the chain link 40 swims around $500mm$ with the cycle of about $0.8s$, and the velocity also floats and drifts, which is caused by the dynamic load.

The acceleration of a chain link is always used for the status indicator of the vibration. Figure 6 presents the acceleration of chain link 40 at any time in the movement of the chain drive system, from which the vibration characteristics of the system can be got. At the same time, the acceleration has rapid change meshing with the sprockets for the meshing impact.

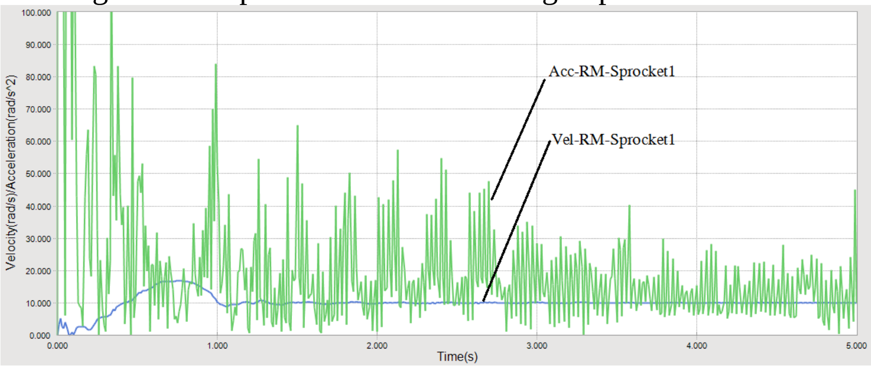


Fig.4 The rotational velocity and acceleration curve of sprocket1

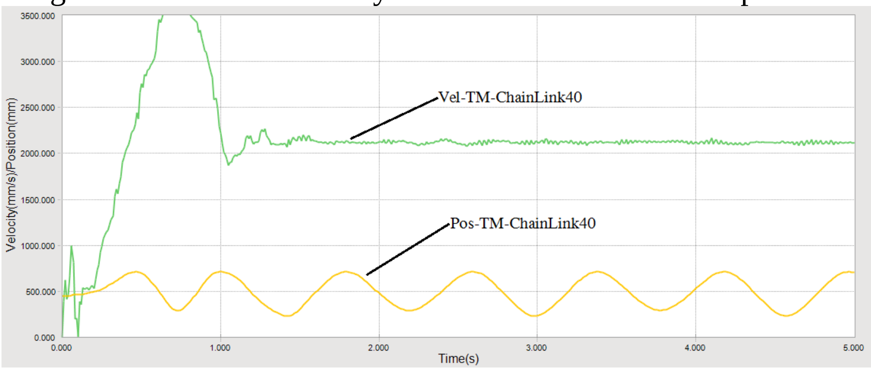


Fig.5 The velocity and position curve of chain link 40

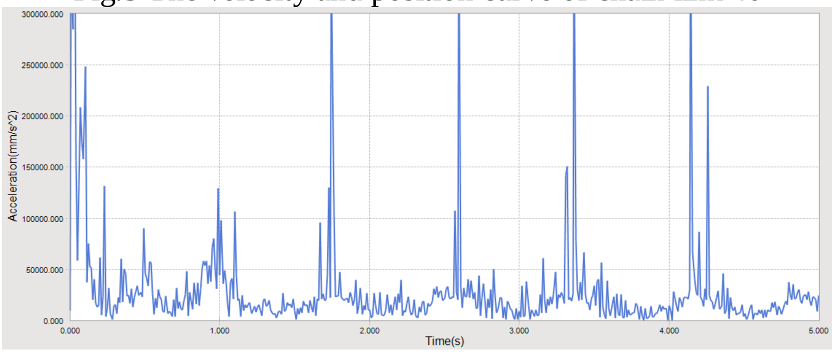


Fig.6 The acceleration curve of chain link 40

In fig. 7 is shown the bushing tension in the links, which connect the two sprockets with the two spans. The forces are shown for a non-dimensional coordinate which goes from 0 to 1, describing the angle of the driving sprocket during one pitch. Meanwhile, the contact force between a chain link and the two sprockets is also shown in fig. 7, in which the contact force has the periodical variation. It is interesting to notice that most of the variation comes from the impact when a chain link comes into contact with the driving sprocket, which is caused by the fact that before the impact the roller which is to mesh with the sprocket has a velocity in a different direction than the contacting flank due to the polygon action.

The results of the simulation and analysis is proved to be precise by comparing the network simulation parameters with the practical data. It is a comprehensive way to figure down the dynamics of a chain system.

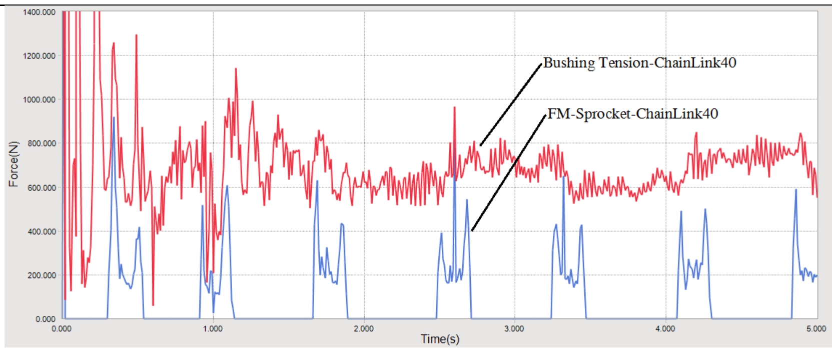


Fig.7 The bushing tension curve of chain link40 and contact force curve between chain link40 and sprockets

## Conclusion

It is got that the dynamic load in the chain cannot be neglected at higher speeds through the generalized recursion theory. Since the oscillation in the tight/slack span is very high at high speeds, it is necessary to understand over all the dynamic characteristic of a roller chain drive system by setting up a chain drive model in RecurDyn software. And movement through the entity model makes it easy to observe the systemic movement, with the parameters such as angular acceleration of the wheels, roller chain link for displacement and speed. Thus a scientific method and theory is provided for the design and precise calculation of the chain drive, contributing to an in-depth study on the dynamic characteristics of a chain system.

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