RECURDYN

# Solution Briefs

## Industry Case Studies

## Electronics



## Aerospace



## Home Appliance



## Construction Machinery



## Agricultural Machinery



## Other Industries

# Optimization of oil lubrication path of HEV transmission systems

**Product: HEV and EV Transmission Systems**
**Analysis Goal: Optimization of lubrication pathway to improve HEV and EV lubrication and cooling**

** HEV: Hybrid-Electric Vehicle, EV: Electric Vehicle*

**Transmission oil plays two roles: lubricating the parts that are rotating at high speed in order to minimize wear, and responding to the heating phenomenon of each part as an appropriate coolant. But if the amount of oil is excessive, it becomes a resistance factor against each rotating part, which may have a negative effect on fuel efficiency. Therefore, oil path inside a transmission has been optimized, and the optimal amount of oil has been determined through visualization and quantification process of the model in order to get the best lubricating and cooling efficiency.**

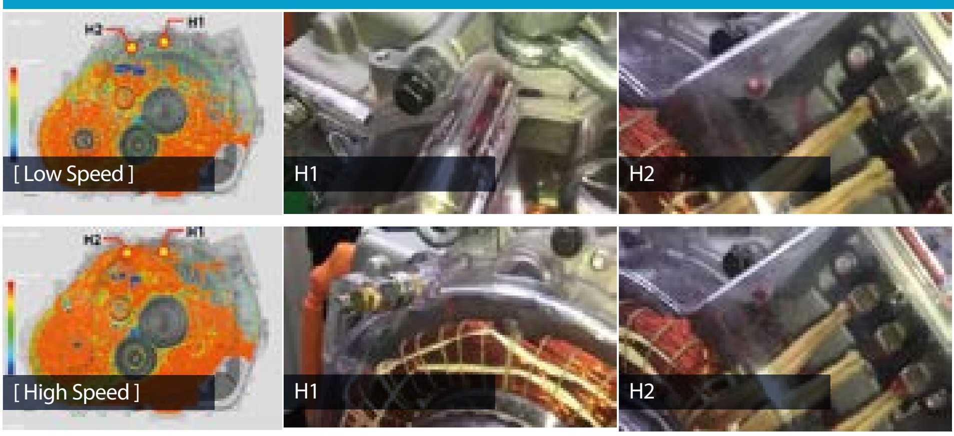
## ◆ Process

① Configuration of dynamic model that includes rotation and other motions using the entire transmission model
② Co-simulation of the transmission oil model and the dynamic model
③ Benchmark test using an actual transmission (check for the quantitative behavior of oil)
④ Comparison between the actual test and analysis results, as well as detailed parameter tuning
⑤ Visual/numerical comparison and analysis of oil behavior effects according to the change of design parameters using the basic virtual model for which detailed parameter tuning has been completed
⑥ Analysis of the result according to various changes in driving conditions (acceleration, deceleration, and steering of a vehicle)

## ◆ Key Technologies for Analysis

- Dynamic modeling of the internal parts of a transmission
- Highly precise fluid modeling according to the characteristics of oil (Particleworks)
- Bi-directional exchange of essential physical quantity between high speed rotating parts and oil (Co-simulation)
- High speed particle simulation technology through GPGPU (Particleworks GPU Solver)
- Calculation of pressure and speed between oil and the related parts with high accuracy

**Comparison between the actual model and analysis regarding oil supply amount**




| Oil Supply | H1 | H2 |
|---|---|---|
| Simulation | X<br>no supply | X<br>no supply |
| Bench Test | X<br>no supply | X<br>no supply |

| Oil Supply | H1 | H2 |
|---|---|---|
| Simulation | △<br>moderate | ◯<br>sufficient |
| Bench Test | △<br>moderate | △<br>moderate |

Images: Courtesy of Hyundai Motors (From the presentation of 'Churning oil path optimization process development' by Chulmin Ahn at VDI Dritev 2018)

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/Gear
- RecurDyn/Bearing
- Particleworks Interface

## ◆ Customer Challenges

- Performance degradation of transmission caused by inefficient oil lubrication
- Demand for improved lubrication performance compared to the existing products
- Difficulty to evaluate the lubrication performance because of the invisibility of transmission inside
- Excessive time and cost to review various designs and operating conditions through prototypes

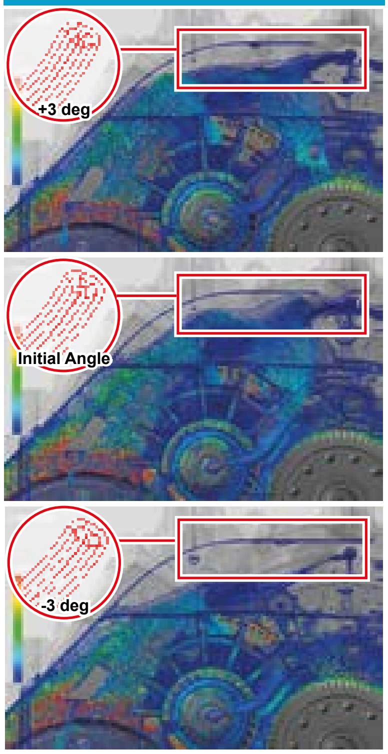
## ◆ Solutions

Time and cost reduction through quantitative performance evaluation of various designs and operating conditions (load torque and oil level) by visualizing inside the transmission using both RecurDyn and Particleworks

## ◆ Outcomes

- Optimization of the oil path configuration that is required in the initial stage of transmission design through highly precise visualization and quantification of the oil flow inside the transmission
- The resistance (Drag) created by oil on each rotating part, which is consistent with the test result, can be estimated in advance.
- The optimal amount of transmission oil can be proposed based on such estimation.

**Change of oil behavior according to the guide configuration**




## ◆ Other Applications

◀ Analysis of changes in load torque according to the difference in temperature of lubricating oil
- Relationship between viscosity and load torque according to the temperature of lubricating oil after turning off the engine input torque
- Analysis of difference in reduction of speed according to lubrication status between the states that have different temperatures (viscosity)

◀ Analysis of the reduction gear train which takes into consideration the viscosity of lubricating oil
- Visualization of the lubricating oil spray which was not possible until now
- The effect of the gear output according to the load of oil viscosity can be designed to be closer to reality

◀ Behavior analysis of lubricating oil spray inside the differential gearbox
- Analysis of load torque when viscous fluid (lubricating oil) has been added to the differential gear train robot

# Prediction of the oil band on spinning wheel of drive-axle assembly

**Product: Drive-Axle**
**Analysis Goal: Predict the shape of the oil band to match physical testing**

**In physical testing the thickness of the fluid film that formed on a spinning wheel of an axle assembly had a distinct shape.**
**A virtual model using Particleworks was established which reproduced the shape of the oil band correctly.**

## ◆ Process

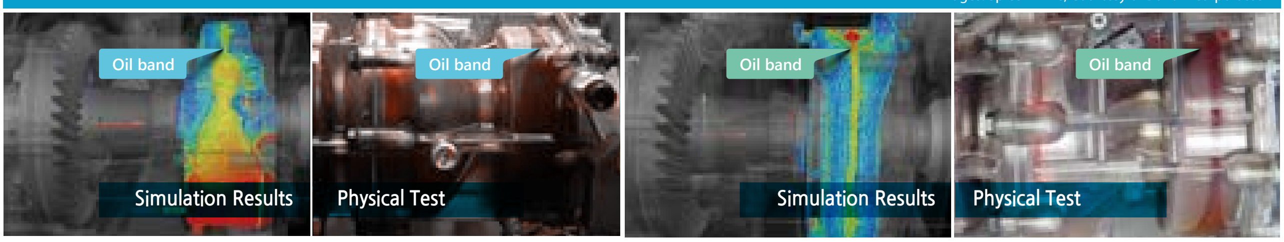
① Creation of the simple 1-chamber model to verify the possibility of reproduction of the oil band
② Simulation of the 1-chamber model and oil model using the fluid particles
③ Model tuning to find the maximum size of the particles to reproduce the oil band to reduce the simulation time
④ Establishing of the 3-chamber model after verifying that the oil band is reproduced with 1.3M particles
⑤ Simulation with 7M particles which takes 12 days without GPU
⑥ Model optimization to finish the simulation within 1~2 days with 2 GPUs

## ◆ Key Technologies for Analysis

- Highly precise fluid modeling according to the characteristics of oil (Particleworks)
- Selection of the optimal size of the particles to reduce the simulation time
- High-speed particle simulation using GPU technology

**Correlation of oil accumulation on surface of a rotating wheel**

Images: Spicer® Axle, Courtesy of Dana Incorporated




## ◆ Toolkits

- RecurDyn/Professional
- Particleworks Interface

## ◆ Customer Challenges

• Need for a CFD tool to reproduce the oil film deposition on the spinning component

## ◆ Solutions

• Design improvement and verification using the virtual model which can reproduce the shape of the oil band

• Visualization and quantitive analysis using Particleworks CFD

## ◆ Outcomes

• Oil-band reproduced by the simulation well matched with the experimental data so that in the future the drag could be predicted using a virtual model.

• Various designs can be tested virtually and the opportunity for design improvements can be identified.

## ◆ Other Applications

◀ Analysis of changes in load torque according to the difference in temperature of lubricating oil

- Relationship between viscosity and load torque according to the temperature of lubricating oil after turning off the engine input torque
- Analysis of difference in reduction of speed according to lubrication status between the states that have different temperatures (viscosity)

◀ Analysis of the reduction gear train which takes into consideration the viscosity of lubricating oil

- Visualization of the lubricating oil spray which was not possible until now
- The effect of the gear output according to the load of oil viscosity can be designed to be closer to reality

◀ Behavior analysis of lubricating oil spray inside the differential gearbox

- Analysis of load torque when viscous fluid (lubricating oil) has been added to the differential gear train robot

# Design improvement of a CV joint boot to increase product life

**Product: CV Joint Boot**
**Analysis Goal: Reproduce the structural failure of the CV joint boot and provide design guidance**

The Mistequay Group, a manufacturer of Constant Velocity (CV) joints had a client who requested a half-shaft that could operate at an increased transmission angle, but the existing boot for the CV joint was already at its operating limit, exhibiting reduced product life at higher transmission angles. Traditional Finite Element Analysis (FEA) was not sufficient for modeling the flexible CV boot in motion because it undergoes complex nonlinear deformation during the combined rotation and bending of the CV joint, and it also makes contact with itself and potentially other half-shaft components during the motion. Because of this, the manufacturer decided to use RecurDyn (Multi Flexible Body Dynamics, or MFBD technology), successfully reproduced the structural failure, and obtained helpful design guidance.

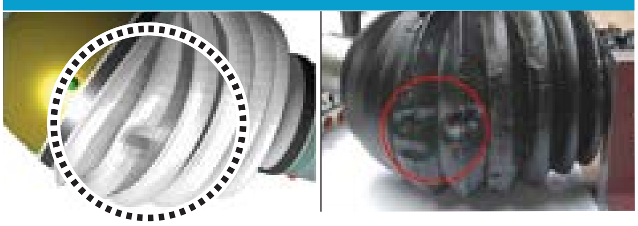
## ◆ Process

① Created a MFBD model that consists of a rigid CV joint model and a flexible boot.
② Configured the boots into its installation positions with respect to the bell and driveshaft.
③ Defined flexible body contacts between the folds of the boots and other locations (including Self-contact).
④ Ran the simulations through transmission angles and rotational speeds of interest.

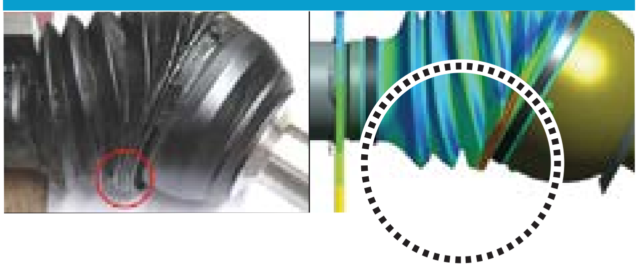
## ◆ Key Technologies for Analysis

- MFBD modeling which consists of rigid bodies and flexible bodies
- Self-contact among the folds of the boots
- Contact between rigid bodies and flexible bodies

RecurDyn correctly validated the formation of dimples



RecurDyn correctly predicted the number of collapsed folds



## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

## ◆ Customer Challenges

• Structural failure under the new operating conditions
• Need to evaluate the dynamic motion at an increased transmission angle
• The complex nonlinearity which is not reproduced with traditional FEA
• Need to improve the design with reasonable time and cost

Rigid model of the boot on the CV half-shaft

## ◆ Solutions

• Modeling and simulation time reduction by MFBD technology which can simulate rigid bodies and flexible bodies together
• Successful reproduction of the structural failure with the nonlinear flexible body and contact algorithm
• Simulation of various designs using an intuitive user interface

Boot mesh to be used for MFBD simulation

## ◆ Outcomes

• RecurDyn could correctly recreate the behavior of the existing design.
• The new boot design does not exhibit the problematic dimpling effect found in the existing design.
• Simulation results provided additional guidance for further design improvements for the new boot.

## ◆ Other Applications

◀ Analysis of a Gear train

• Dynamic analysis of gears that are represented as flexible bodies
• Analysis of transmission to check contact force as a function of the shape of gear teeth

◀ Analysis of an Excavator

• Analyze the characteristics of the vibration that occurs on the vehicle lower frame when it runs on a rough road
• Evaluation of the load applied to the arm and vehicle upper frame during excavating to improve product durability

# Order tracking of gear mesh vibration in a speed reducer

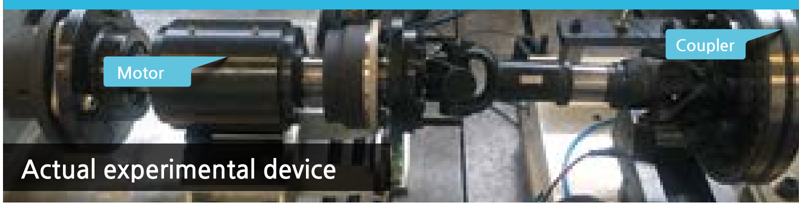
**Product: Speed Reducer**
**Analysis Goal: Reproduce and analyze the vibration of a speed reducer that includes planetary gear**

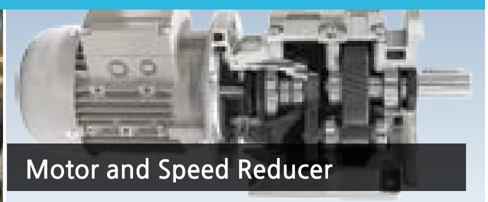
**In order to design a low-vibration system, vibration characteristics were reproduced through computer simulation. Vibration characteristics included resonance conditions that might occur depending on the number of revolutions and meshing frequencies of a reduction gear model that includes a planetary gear set driven by an electric motor. After building and simulating a 3D model of the speed reducer, the simulation result was compared with experimental data to verify the accuracy. Through this process, the possibility of verification using only virtual models was examined for use during the early stages of development where physical products are not prepared.**

## ◆ Process

① Checked the vibration order of gear meshing frequency using a formula based on the speed reducer gear set information.
② Mounted the actual speed reducer, including the planetary gear set, onto a dynamo equipped with a vibration measuring device (accelerometer and microphone).
③ The speed reducer was accelerated from a stationary state to a specific RPM, and then the transient vibration characteristics of the model (vibration order) was analyzed.
④ Built a 3D dynamic model and ran simulations under the same operating conditions as the physical test, then analyzed the transient vibration characteristics of the virtual model.
⑤ Validated the simulation results by comparing the vibration characteristics obtained from methods 1 ~ 4 above.
⑥ Confirmed that the vibration characteristics of the actual speed reducer could be reproduced with 3D dynamic model simulation. – The Campbell diagram results, such as the order lines and their tendencies, reproduced by the simulation matched the experimental data and the mathematical results of the actual speed reducer.

Test device for measuring vibration characteristics




## ◆ Key Technologies for Analysis

- Specialized gear and bearing UI for high accuracy dynamic simulation of speed reducer
- Flexible body modeling of the speed reducer housing accurately measures the vibration characteristics on the housing surface
- Flexible body modeling of the shaft accounts for the deformation of the rotating shaft
- Specialized Gear Contact algorithm for accurate gear contact analysis
- Gear Meta model technique for faster gear contact analysis
- High speed flexible body technology (RFlex) using mode shapes of the housing instead of the entire DOFs of the nodes to improve the simulation performance
- Intuitive Campbell diagram UI for order tracking analysis of the rotating system

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/GearKS
- RecurDyn/BearingKS
- RecurDyn/Shaft
- RecurDyn/RFlex

## ◆ Customer Challenges

- Need alternatives to the current process of using physical prototypes in order to reduce development time and cost
- Need for simulation technology that can reproduce the vibration characteristics of complex gearbox systems including planetary gear
- Need for intuitive post-processing technology to analyze the vibration characteristics quickly

## ◆ Solutions

- Fast modeling of the 3D dynamic model using specialized gear and bearing UI
- Vibration characteristics identification using simulation that matches the experimental data
- Checking the frequency band causing resonance in advance through intuitive post-processing of the simulation and results

## ◆ Outcomes

- The possibility of vibration analysis using virtual model was confirmed.
- It was confirmed that simulation can reduce time and cost for physical tests as well as for system design improvements.

## ◆ Other Applications

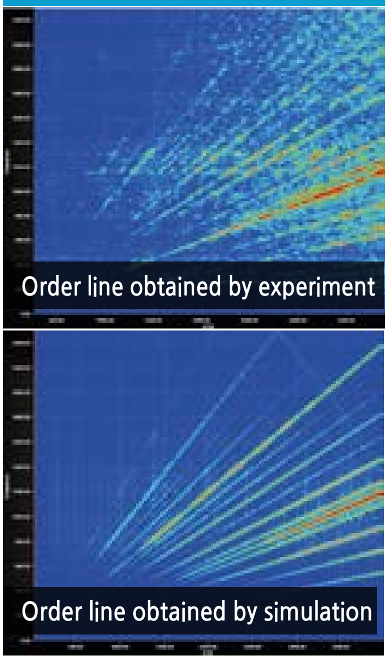
◀ Transmission simulation using RecurDyn

- Dynamic simulation of transmission with multiple gears
- Analysis of gears' dynamic behavior when shifting gears

◀ Differential Gear Simulation including lubrication oil

- MBD x CFD Co-simulation using RecurDyn and Particleworks
- The interaction between the gears and oil can be analyzed

**Comparison between experiment and simulation results**




Speed Reducer including planetary gear set

# Scooter engine valve design improvements

**Product: Engine valve**
**Analysis Goal: To reduce the carbon deposits around the engine inlet ports**

A scooter manufacturer desires to reduce engine failure by reducing carbon deposits around the inlet ports. The inlet valves are designed to be rotated by the camshaft movement when they are opened to prevent the build-up of carbon. At high rpm, the valves rotate well. However, at low rpm, the valves do not rotate adequately to prevent carbon build-up. As a result, under low rpm use, there can be significant carbon deposits around the inlet ports, which can lead to engine failure. RecurDyn was used to identify that valve contact surface shape is the key to trigger valve rotation. Then RecurDyn was used to design and validate a different, improved valve contact surface shape that can enable sufficient valve rotation even at low rpm to prevent carbon deposits from forming.

## ◆ Process

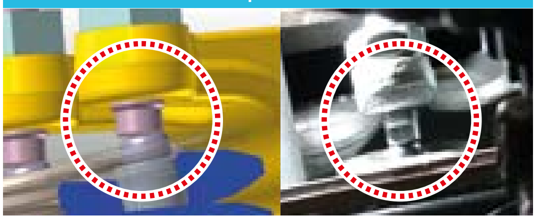
① Created an MBD model including contact, springs, and cam to reproduce and validate the valve rotation
② Ran simulations at various rpms of interest
③ Analyzed the valve rotation at different speeds
④ Analyzed the valve rotation with different valve contact surface shapes

The carbon deposits around the engine inlet ports

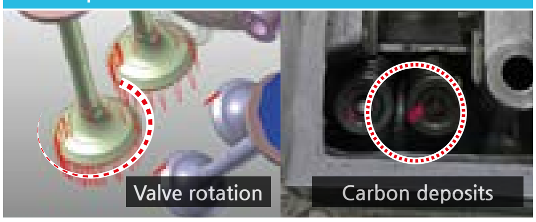
## ◆ Key Technologies for Analysis

- Rigid multi-body dynamics used to quickly perform multiple simulations with different shapes and rpms
- Nonlinear contact algorithm to calculate the contact forces between complex geometries quickly and accurately
- Trajectory display to visually verify the rotational motion of the valves

RecurDyn correctly reproduced the valve behavior using various contact surface shapes



RecurDyn correctly reproduced the valve rotation direction of the experimental result

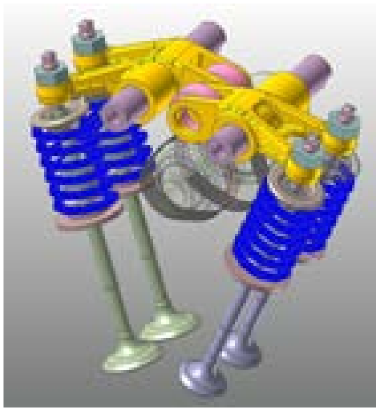



## ◆ Toolkits

- RecurDyn/Professional

## Customer Challenges

- Trial & error using physical prototypes requires more than half a year to achieve design improvement.
- Measuring and monitoring the valve rotation using experiment are very difficult.
- Complex contact behavior is not supported with traditional CAD software.
- Valve contact surface shape improvement must be achievable with reasonable time and cost.



Model with rigid body valves and spring forces

## Solutions

- Fast modeling and simulation using professional dynamics software
- Fast and accurate simulation using powerful contact algorithm
- Simple and convenient visualization of results compared to cumbersome measurement and monitoring of physical experiments
- Quantitative evaluation of the effect of contact surface shape and visual verification of valve rotation through trajectory display

3D contact surfaces

## Outcomes

- RecurDyn correctly recreated valve rotation for various camshaft rpms
- The new valve contact surface shape was validated using simulation
- Simulation results provided guidance for further design improvements for the new engine

## Other Applications

◀ Analysis of a Gear train

- Dynamic analysis of gears that are represented as flexible bodies
- Transmission analysis to check contact force as a function of the shape of gear teeth

◀ Transmission simulation using RecurDyn

- Dynamic simulation of transmission with multiple gears
- Analysis of gears' dynamic behavior when shifting gears

◀ Watch the animation of engine valve

# Statistical relation between road roughness and accumulated fatigue in transportation of packaged freight

**Product: Packaged freight**

**Analysis Goal: Effect of road roughness to accumulated fatigue of package freight in transportation by truck**

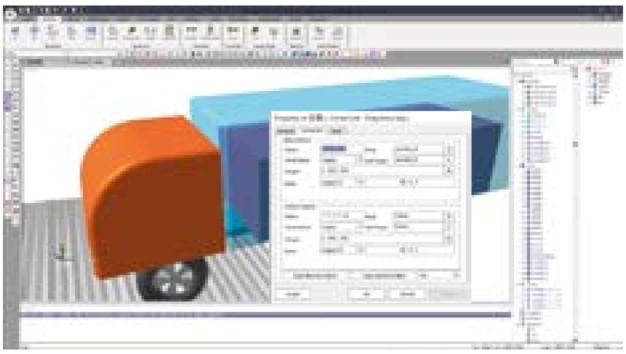
**In the transportation of packaged freight by truck, the magnitude of damage depends largely on the roughness of the road. Because the road surface shape is complex, it is often expressed by the power spectrum density of a typical road surface height. Damage is expressed in accumulated fatigue. However, the relationship between damage and the road surface shape is not clear. Here, a computational analysis of a truck loaded with packaged freight driving over a road is performed using RecurDyn. The road surface shape is based on the theory of non-Gaussian distribution that was created from the power spectrum density of the surface height set by the Japanese Industrial Standards (JIS). Kurtosis was used as an index to indicate the road surface roughness, and the relationship between the kurtosis and the accumulated fatigue obtained from the vibration acceleration of the packaged freight on the truck was analyzed.**

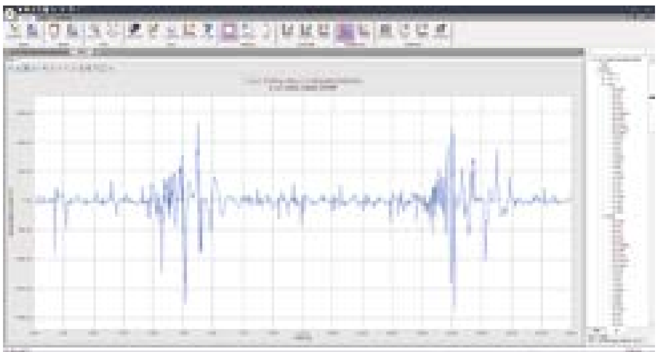
## ◆ Process

① Create RecurDyn model of typical package transportation truck.
② Generate non-Gaussian random road profile in ProcessNet from a road height PSD in JIS standard.
③ Create road file for GRoad from that random road profile.
④ Perform driving simulation of truck using the above conditions.
⑤ Calculate accumulated fatigue of the packaged freight.
⑥ Perform statistical analysis.

## ◆ Key Technologies for Analysis

- Truck model for driving simulation on 3D road
- Tire model for driving simulation on 3D road
- Road model for driving simulation on 3D road
- 3D road profile in GRoad generated using random vibration theory
- Statistical analysis between Kurtosis of road profile and accumulated fatigue of freight acceleration



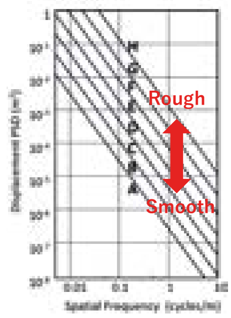


## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/GTire
- RecurDyn/ProcessNet

## ◆ Customer Challenges

- Damage evaluation of packaged freight in transportation relies on simulating bench tests because of difficulty of using actual driving tests.
- JIS provides road roughness in frequency domain but no actual shape is provided.
- The relationship between the fatigue of packaged freight and the road surface is not clear.

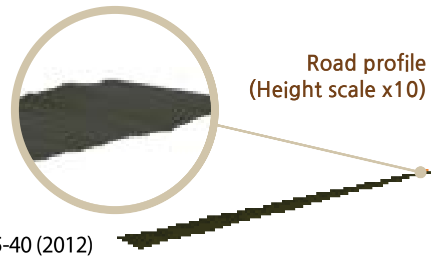



## ◆ Solutions

- Road profile is created based on non-Gaussian random vibration theory[1] programmed into RecurDyn/ProcessNet .
- Truck driving simulation model is created with GTire in RecurDyn/Tire and UATire.
- Accumulated fatigue for damage is calculated from zero-cross-peak count[2] of package acceleration on truck and studied in relation with kurtosis of road profile.

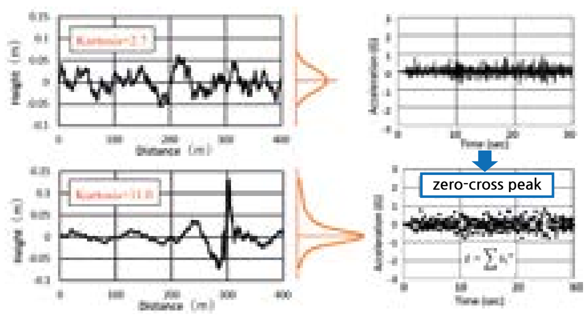
(1) A.Hosoyama, K.Saito, T.Nakajima. Non-Gaussian random vibrations using kurtosis, Proceedings of 18th IAPRI World Packaging Conference, San Louis Obispo (CA), USA, pp 35-40 (2012)

(2) zero-cross-peak count (ISO 16750-3_2007)




## ◆ Outcomes

- Road model for driving simulation in RecurDyn can be generated from arbitrary road properties in frequency domain.
- Various road profiles of different kurtosis can be defined from one PSD road specification.
- It is now possible to estimate quantitative damage β from road profile kurtosis.




## ◆ Other Applications

◀ Driving simulation of passenger car on 3D road

- Passenger comfort
- Steering performance

# The analysis of the noise and vibration of drum brake systems

**Product: Drum Brake Systems**
**Analysis Goal: Evaluate the vibration characteristics of a drum brake system and improve its design**

Drum brakes, which are widely used in trucks, buses, and some passenger vehicles, slow a vehicle using friction between semicircular brake shoes connected to the axle or suspension of the vehicle and the inside of a cylindrical drum mounted on the wheel. The friction coefficient between the shoes and the drum is a tunable characteristic that affects both the stopping performance and the vibration characteristics of the brake. A higher friction coefficient reduces the required forces acting on the shoes, but it also increases the vibration and reduces the stability of the brake system. To optimize the brake design, the multi flexible body dynamics software RecurDyn was used to reproduce the friction and vibration of the drum brake system during operation and evaluate its vibration and braking performance. A model of the brake system was created as a virtual twin of a physical brake system. This virtual twin was used to evaluate 2 different brake system designs.

## ◆ Process

① Created an MBD model of the drum brake system including the axle, brake shoes, and drum to reproduce its dynamic behavior.

② Created flexible bodies to predict the deformation and stress of the drum and shoes.

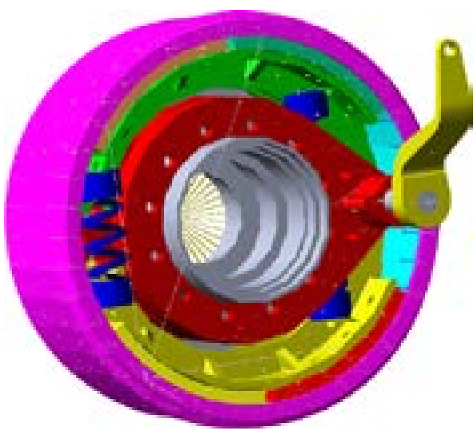
③ Analyzed the vibration characteristics under different friction coefficients between drum and shoes.

④ Evaluated the braking performance of 2 different designs with the same friction coefficient.

Drum brake
Unrelated to this article.

## ◆ Key Technologies for Analysis

- Multi-body dynamics technology to predict the behavior of drum brakes
- Nonlinear contact algorithm to calculate the contact forces including friction between rigid bodies and flexible bodies
- Multi Flexible Body Dynamics (MFBD) technology that can accurately reproduce the deformation and stress of the drum and shoes as well as the motion of the brake system


RecurDyn model of drum brake system

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/GTire
- RecurDyn/ProcessNet

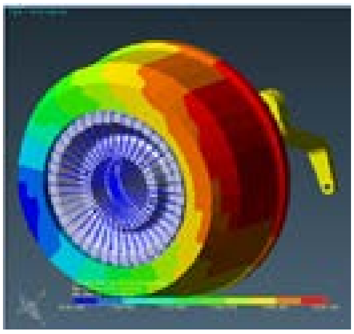
Xuzhou Meritor Axle Co., Ltd
China Postdoctoral Science Foundation funded project -No. 2012M521003
the National Basic Research Program of China-No. 2014CB049401

## ◆ Customer Challenges

- Need to identify the source of and improve the noise and vibration from the drum brake
- Early validation to verify if a new design meets the required braking performance specification
- Difficulty in analyzing the deformations and stresses in various parts of the drum brake system

## ◆ Solutions

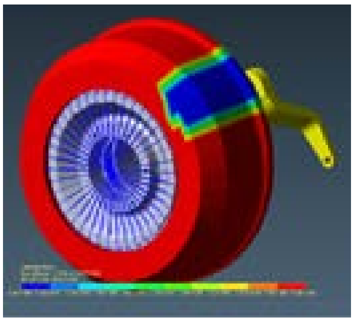
- The nonlinear contact algorithm that could successfully reproduce the vibration caused by the contact between the shoes and drum
- Quantitative evaluation of the change in vibration characteristics from a change in the friction coefficient
- Accurate prediction of the deformation and stress of the drum over time using transient MFBD technology
- Prediction of the braking performance difference between 2 different designs using virtual model



Contour plot of the deformation of the drum

## ◆ Outcomes

- New designs could be validated in an early stage using virtual models.
- Simulation results had good agreement with the physical results.
- After creating a virtual twin of the brake system in RecurDyn, this model can be used in the future for further development and analyses of the brake system.



Contour plot of the stress on the drum

## ◆ Other Applications

◀ Parking brake simulation

◀ Brake simulation using flexible bodies

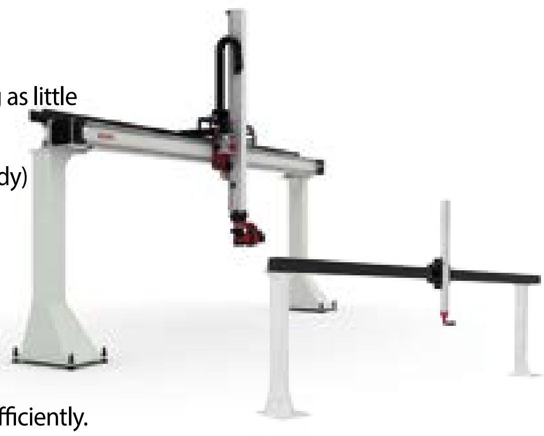
# Analysis of structural oscillations on linear handling axes

**Product: Gantry System**
**Analysis Goal: Establishing the digital twin model of the linear handling axes to analyze its structural oscillations**

**The current trend to lightweight structures in handling machines offers many advantages (e.g. less energy consumption, faster movements), but due to the decreased stiffness of these structures, more effort needs to be done considering positioning accuracy, including the control of structural oscillations. In order to guarantee the desired accuracy, and also to deepen the understanding of the complex couplings between motions and forces inside its own machines, Güdel decided to enhance its development process by implementing the flexible multi body dynamics simulation tool, RecurDyn.**

## ◆ Process

① To reduce the computational effort, the Gantry System was modeled using as little parameters as possible.
② A flexible body based on linear modes (Reduced Flexible body or RFlex body) was used to represent the foot holder and carriage as a combination of mode shapes.
③ The axes were modeled as beam elements and the tool-center point is modeled as a rigid body.
④ With RecurDyn/MachineTool, the complex coupling between forces and motion related to the rack and pinion could be simulated accurately and efficiently.


Digital twin model of the linear handling axes

## ◆ Key Technologies for Analysis

- The flexibility of the system needs to be considered to evaluate the position accuracy and oscillations.
- The arbitrary combination of many configurations of the Güdel machine could be modeled easily.

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/RFlexGen
- RecurDyn/RFlex
- RecurDyn/MachineTool

GÜDEL

## ◆ Customer Challenges

- Need for a method to implement the new ideas easily and analyze them with reduced building of expensive prototypes
- Modeling of all the modules (the complete system) is indispensable to achieve the desired position accuracy and the better understanding of the oscillations enforced by the complex coupling of forces and motions.

## ◆ Solutions

- With RecurDyn/RFlex and RecurDyn/MachineTool, the entire system can be simulated using a simplified process, and showed good match with the experimental data.
- With this RecurDyn model, all components can be easily modeled and the system behavior can be predicted.


## ◆ Outcomes

- Many unknown aspects could be understood and thus improvements could be achieved from combining the experimental data of the Gantry System with the derived knowledge from the modeling.
- Characteristics of the actuation force calculated by RecurDyn using a predefined acceleration setpoint (red), different parameter settings were studied and compared to an experimental measurement (blue)

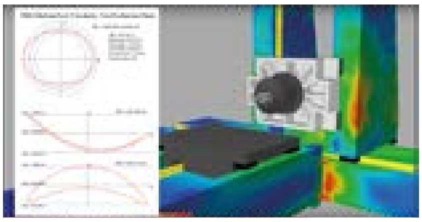
## ◆ Other Applications

◀ Analysis of an industrial Robot Arm

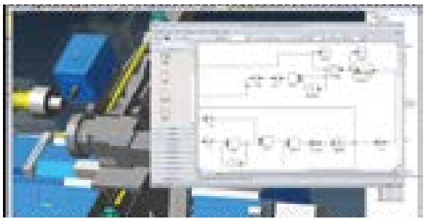
- Checks the dynamic behavior of a robot arm that includes a control system.
- Analyzes the vibrations and loads applied to the robot's major points to establish a stable production process.
- Applies to its structural analysis the load conditions that change when you change the design of the robot system or the operating conditions of an actuator.

◀ Circularity Test of the Machine Tool using RecurDyn/MachineTool

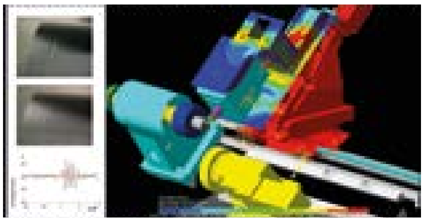
- Functions for standard operations such as ISO circularity test are available
- Analysis of a motor with controller
- Analysis of ball screw motion drives, linear guides and bearings



Circularity test evaluation using RecurDyn/MachineTool



Control simulation of the Lathe using RecurDyn and CoLink



High-fidelity simulation using RecurDyn/MachineTool

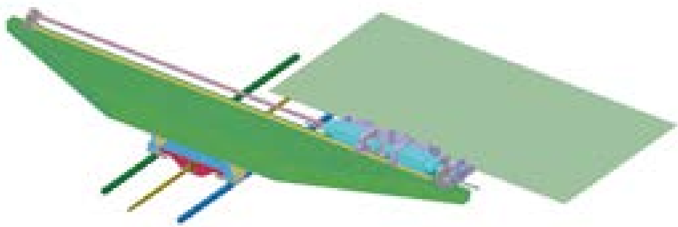
# Virtual prototyping of sheet metal processing machine to improve capacity and precision

**Product: Sheet Metal Processing Machine (Punching Machine)**
**Analysis Goal: Accurately predict the behavior of the dynamic effects caused by the coupling of the inertial load with the structural flexibility under various operating conditions**

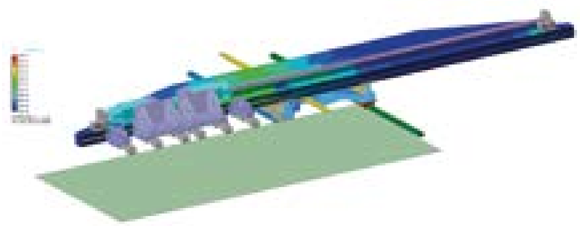
**The design of the Sheet Metal Processing Machine must take into account the dynamic effects caused by the coupling of the inertial load with the structural flexibility. During acceleration and deceleration, the machine structure undergoes small deformations that can cause oscillations at the end of the movement, especially with higher payloads. RecurDyn provides a robust tool for efficiently creating and analyzing virtual prototypes capable of reproducing the dynamic behavior of the machine under different operating conditions.**

## ◆ Process

① Set up a Multi Flexible Body Dynamic model of the Sheet Metal Processing Machine.
② Implement both linear guides and ball screws using the dedicated RecurDyn/MachineTool toolkit.
③ Implement flexible bodies through the linear approach based on the modal condensation (Reduced Flexible body).
④ Create a sub-mechanism that reproduces the dynamic effects of the brushes table on to the moved metal sheet.
⑤ Use the powerful RecurDyn expression editor to develop a custom non-linear analytical model that controls both normal and shear reaction forces.
⑥ Simulate the dynamic behavior of the machine under different operating conditions.
⑦ Post process outputs and identify the main goals.



Dynamic model of sheet metal processing machine



Simulation result

## ◆ Key Technologies for Analysis

- MFBD technology, which efficiently handles the flexibility of the system to evaluate the tool position with high accuracy
- Robust solver that achieves the goals without needing powerful HPC and without exhibiting convergence problems

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/RFlex (Reduced-Flex)
- RecurDyn/MachineTool

A case from EnginSoft Newsletter #4, year 2019.
Courtesy of EnginSoft S.p.A., Italy (www.enginsoft.com)

## ◆ Customer Challenges

- The market demands machines with increased payloads, shorter cycle times (capacity) and higher precision.
- Machines have to be designed and built in a shorter time, while keeping the development costs under control.

## ◆ Solutions

- Introduce the dynamic simulation in the design chain to reduce the number of experimental tests / prototypes and to achieve a higher knowledge of the dynamic behavior of the machines.

## ◆ Outcomes

- The dynamic behavior of the punching machines is successfully and accurately reproduced.
- The design of the machine control systems is improved which plays a crucial role in the final performance.
- The number of design alternatives that will be tested on a physical prototype could be reduced.
- RecurDyn can answer many design questions such as:
  - Why is the system vibrating that way?
  - Where is the stiffness more needed?
  - Can we reduce the thickness of guides arms?
  - Is the system damped enough?

  And more.

## ◆ Other Applications

◀ LCD Transfer Robot simulation using RecurDyn (MFBD and Control)
- Comparison of different operating conditions (different LCD sizes)
- Simulation of abnormal operations
- Simulation including controller

◀ High Pressure Cleaning Robot simulation using RecurDyn (MFBD and CFD coupling)
- Simulation including controller
- Evaluation of optimal cleaning conditions using a coupling with CFD
- Stress assessment using MFBD

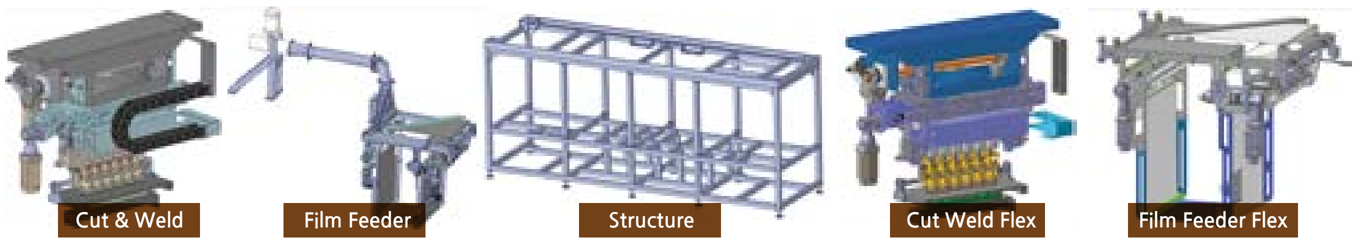
# Improving the capacity of a coffee capsule machine using multi-body simulation

**Product: Coffee capsule machine**
**Analysis Goal: Increase capacity by 25% without increasing overall costs and energy efficiency**

**Capacity is one of the most important features of an automatic packaging machine. OPEM's designers are constantly looking for new design solutions that will allow the company to remain competitive. This project deals with the optimization of a machine for the production of coffee capsules. The main objective was to increase the capacity by 25%, without affecting the general architecture, the size of parts and the energetic efficiency of the machine. The objectives were achieved by optimizing the motion laws of all actuators. A large number of Multi-Flexible Body Dynamics simulations were performed in RecurDyn to check the effects of the optimized laws on the system behavior.**

## ◆ Process

① Motion laws are applied to all ideal motors equipping the machine. Motion laws are designed and optimized to guarantee continuity and lowest possible accelerations, while achieving the desired displacements at the desired instants.
② The rigid multi-body model of the entire machine is used to check that the motion laws are properly synchronized. The same model is also used to measure the power demand which becomes the main information used to choose proper motors.
③ This model includes a Full Flex representation of the thin film that is used to seal the capsules.
④ The multi-flexible body model of the entire machine is used to check if the positions of tools and capsules are guaranteed even when the structures deform in dynamic conditions.
⑤ This model is also used to calculate the dynamic reaction forces at the constraints that connect each machine sub-system to the main frame.
⑥ The loads obtained from the multi-flexible body model are used for structural assessment (strength and fatigue) using other Finite Element programs.




## ◆ Key Technologies for Analysis

- Rigid multi-body dynamics is used to optimize motion laws and calculate power demand since it is very fast. Multiple iterations take little time to perform.
- Multi-flexible body dynamics is used to check that all bodies (tools, capsules, and film) are in the expected (and required) position in severe dynamic conditions.
- Hundreds of non-linear contacts are used to describe the interaction between tools, capsules, and film.

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex
- RecurDyn/Chain

OPEM

A case from EnginSoft Newsletter #3, year 2019.
Courtesy of EnginSoft S.p.A., Italy (www.enginsoft.com).

## ◆ Customer Challenges

- The market demands packaging machines with increased capacity, reliability, and small dimensions.
- Machines have to be competitive in terms of cost.
- Many contacts are used to represent the complex chain mechanism.
- Many numbers of simulations are required for optimization because optimization of motion laws (cams and controlled electric drivers) is the key to achieving higher capacity without increasing the power demand and the dynamic loads.

## ◆ Solutions

- Rigid multi-body simulation is the most suitable approach to check the correctness of the motion laws, as each simulation takes a very short time. Running multiple iterations to optimize the laws is easy and can be done at no cost.
- Flexible multi-body (reduced flex and full flex) is necessary to check the effectiveness of the proposed design solutions. Although some components of the machine are largely flexible, the relative positioning of the capsule, film and tools must also be guaranteed in severe dynamic conditions.
- RecurDyn Chain toolkit allows for the easy modeling of the chain mechanism and the large number of contacts can be calculated quickly.

## ◆ Outcomes

- The capacity of the coffee capsule machine production has been increased by 25%.
- New motion laws have been designed and verified.
- The structure of the main frame has been simplified.

## ◆ Other Applications

◀ Printer

- Paper feed application for adjusting paper edge alignment
- Roller engagement time control is used with RecurDyn MFBD technology

◀ Forklift simulation with chain assemblies

- Chain assemblies consist of 128 links and contact

# Virtual drop test of a hard drive and its cushioning material for transportation

**Product: External hard drive with packaged with cushioning material**
**Analysis Goal: Evaluation of cushioning material to absorb the impact of the falling hard drive**

**Here, an external hard drive protected by cushioning material and a drop test machine were modeled using RecurDyn in accordance with the drop test, JIS standard Z0200 and Z0202. The analysis evaluated the performance of the Styrofoam cushioning material. The cushioning material was modeled as an FFlex body and its stress and the acceleration of hard drives were calculated. The predicted acceleration of the hard drive matched the results of an actual drop test well.**

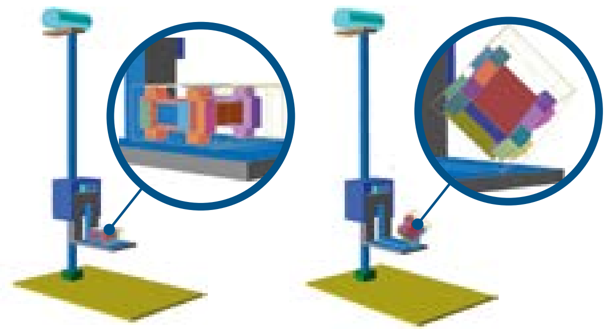
## ◆ Process

① Import CAD data of hard drive and cushioning materials (Styrofoam, Corrugated box).
② Create FFlex body for cushioning material and define Geo contact between hard drive and cushioning material.
③ Create RecurDyn model of drop test machine.
④ Analyze model in accordance with JIS standard test conditions.

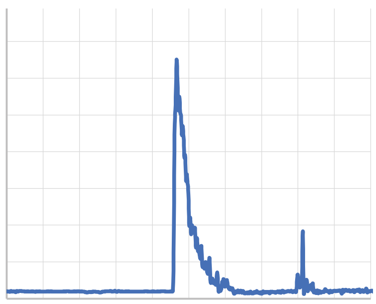
## ◆ Key Technologies for Analysis

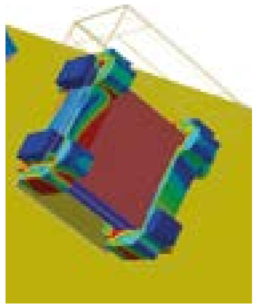
- MFBD model for evaluation of cushioning material to protect hard drive
- Contact between cushioning material flexible body, hard drive, and the corrugated box
- Contact parameter identification to reproduce the acceleration of hard drives during drop test

**Analysis condition according to JIS standard**



**Acceleration of hard drives and stress of cushioning material**





## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

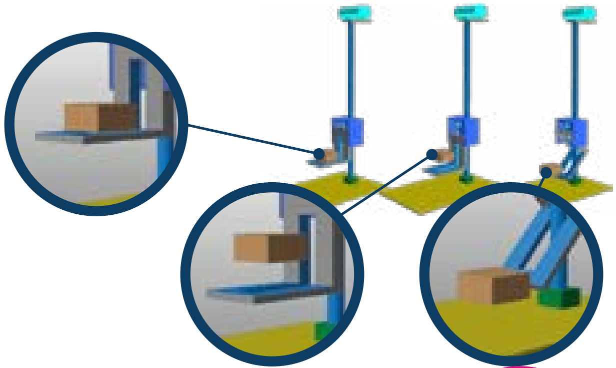
## ◆ Customer Challenges

- Difficulty in valuating effect of cushioning material on the acceleration in the hard drive using physical drop test
- Difficulty in determining packing configurations that cause damage to the cushioning material
- Impossible to measure acceleration at arbitrary locations in the hard drive
- High expense and time required to design, perform, and analyze physical drop tests

http://www.lansmont.com/products/drop/

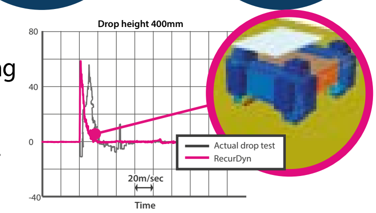
## ◆ Solutions

- Geo contacts between hard drive and cushion or corrugated box (Contact stiffness was estimated from cushioning material data)
- Cushioning material modeled using FFlex body to evaluate the stress and deformation
- Drop test machine included in analysis model



## ◆ Outcomes

- MFBD model accurately reproduced measured physical drop test accelerations.
- Though impossible with a physical drop test, using FFlex, the contact state of the cushioning material became clear.
- Theoretical analysis of behavior of cushioning material becomes much more sophisticated.
- Expect a significant reduction in labor to design hard disk cushioning.




## ◆ Other Applications

◀ Vibration exciter for transportation packaging design

- Test machine to evaluate package design
- Vibration on truck bed in transportation
- Cargo collapse due to earthquake in warehouse

http://www.lansmont.com/

# Vertical, roll, and pitch vibration, rubbing, and collapse analysis of stacked corrugated boxes on a pallet

**Product: Stacking corrugated box on pallet**
**Analysis Goal: Measures to prevent abrasion damage and load collapse stacked on pallet during transportation and storage**

**Corrugated boxes are commonly used to pack electronic products and consumer goods for transportation. Corrugated boxes are often stacked on pallets during transportation and storage. Vibration during transportation or earthquakes of stacked boxes on pallets can cause collapse due to box contact. Vibration tables are often used for the evaluation of box performance. Industry standards for vertical vibration testing also exist, but recently, 3 degree-of-freedom vibration testing which includes pitch and roll has become popular. Here, stacked corrugated boxes on a 3-DOF vibration table was modeled in RecurDyn. 3-DOF motion of the vibration table was modeled using RecurDyn actuators. The contact, rubbing, and collapse caused by roll and pitch motions was simulated.**

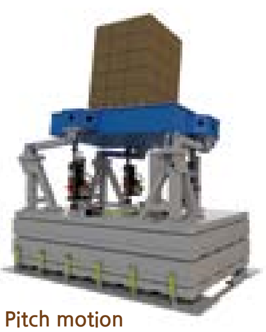
## ◆ Process

① Create RecurDyn model of 3-DOF vibration table that supports vertical, roll and pitch motion.
② Create RecurDyn model of stacked corrugated boxes on pallet.
③ Create Geo contacts between pallet and corrugated boxes and between boxes.
④ Create body to represent the film to prevent stacked boxes from collapsing.
⑤ Apply motion to actuators of 3-DOF vibration table to generate vertical, roll, and pitch motions.

## ◆ Key Technologies for Analysis

- Joints between components to accurately reproduce the pitch and roll behavior of a 3-DOF vibration tester
- Kinematic model to apply prescribed vibration independent of the stack mass
- Modeling technique to mimic collapse prevention film

| 3 DOF Vibration Table | RecurDyn Model |
|---|---|



Pitch motion

Static

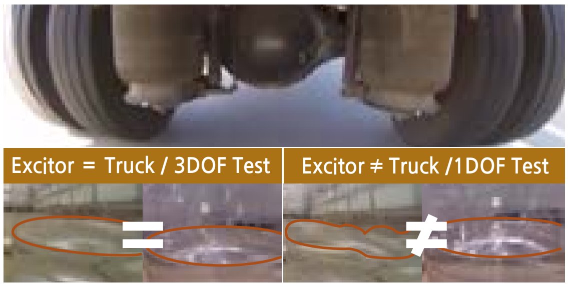

Roll motion

## ◆ Toolkits

- RecurDyn/Professional

## ◆ Customer Challenges

- Characters printed on corrugated boxes stacked on pallets disappear during transportation, suspected to be due to rubbing.
- Stacked boxes sometimes collapse during transportation.
- The vibration of cargo during truck transportation cannot be accurately reproduced by 1-DOF vibration tables.
- Testing with physical vibration tables requires too much time and cost.



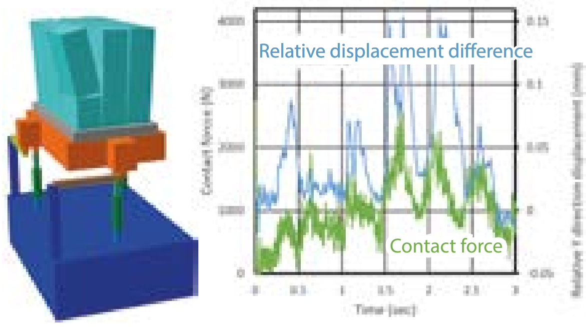

Behavior comparison of water in bottles
(Vibration table vs. Truck)

## ◆ Solutions

- 3-DOF Vibration table testing environment loaded with stacked corrugated boxes was reproduced in RecurDyn.
- Contacts between corrugated boxes and vibration table were modeled with Geo contact.
- The collapse prevention wrapping film was simulated with a low contact stiffness.

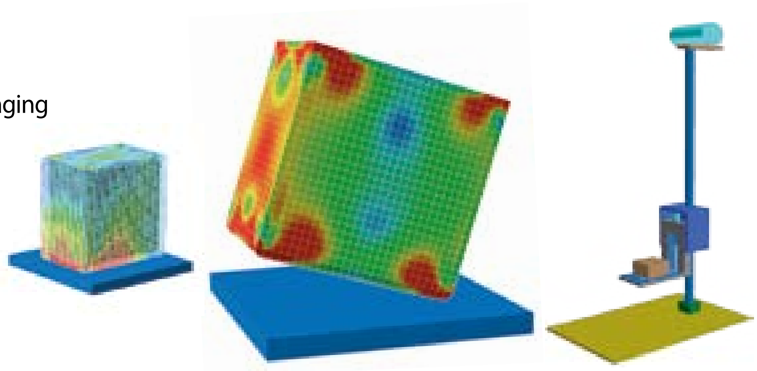
## ◆ Outcomes

- The roll and pitch motions were accurately reproduced in the RecurDyn model by modeling the actuator displacements.
- Corrugated boxes penetrating through the film and stack collapse was accurately simulated.
- Contact forces between boxes, which is believed to be the source of rubbing, were reasonably predicted.




## ◆ Other Applications

◀ Impact damage evaluation
- Damage of product inside of packaging
- Damage of corrugated box



# Investigating the operating scenarios of a planetary strander through multi-body simulations

**Product: Planetary Stranding Machines**
**Purpose of Analysis: Predict both maximum internal loads and the highest power demand**

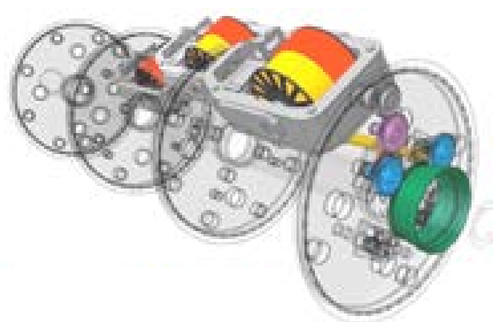
Planetary standers are large machines used to produce steel strands and ropes in single- or multi-operation processes. These machines are designed to combine many stranding elements while twisting them around a common axis. The stranding elements are initially wound on reels, which are mounted on rotating cages. The extraordinary moving masses and the risks that would result from a structural failure are critical issues in the design of standers. Mario Frigerio S.p.A., Italy, which is a leading manufacturer of standers, was asked to develop customized planetary standers that had to meet exceptional specifications. RecurDyn software was used to virtually analyze all the possible operating scenarios. Simulation results provided both the maximum loads for parts, sizing and, at the same time, the required information for choosing the huge electric motor powering the machine.

## ◆ Process

① Imported the CAD geometry which included about 100 bodies. Bodies were connected using many types of kinematical joints.
② Friction on rotating shafts was considered.
③ Parameterized spools were built internally to reproduce different loading conditions (i.e. different types of ropes that the machine can produce).
④ All planetary gear units were modeled through the coupler entities.
⑤ 64 load cases were considered, focusing on 3 working phases: acceleration, constant speed, and emergency braking.

## ◆ Key Technologies for Analysis

- Kinematic joints with friction
- Parameterized geometries for reels
- Coupler constraints for gear couplings
- Batch simulation of multiple operating scenarios



RecurDyn model of planetary stranding machine

## ◆ Toolkits

- RecurDyn/Professional

## ◆ Customer Challenges

- Wide range of difficult-to-predict operating conditions specific to the customer's needs
- Extreme dynamics due to the unbalanced reels rotating at relatively high speeds
- Identifying the optimal motor capacity
  - If too small, the machine to not work in some operating conditions
  - If too large, it would increase the total cost with no benefits.

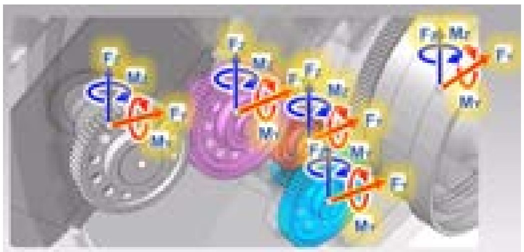
## ◆ Solutions

- Professional multibody simulation can quickly calculate the power peaks in dynamic conditions.
- Parameterized geometries allow for fast change of working scenarios.
- Calculation of the inertial loads and reaction torques is automatic.

**Planetary Stranding Machine**

## ◆ Outcomes

- The maximum (sizing) loads acting on each machine component were obtained for proper structural verification.
- The crucial information required to choose appropriate electric motors was obtained by processing the simulation results from multiple load cases.



**Reaction torques and forces on planetary gear units**

## ◆ Other Applications

◀ Improving the capacity of a coffee capsule machine using multi-body simulation

- Verification of the motion laws for the design improvement
- Simplifying the structure of the main frame using simulation

◀ Virtual prototyping of sheet metal processing machine to improve capacity and precision

- Reproduction of the dynamic behavior of the sheet metal processing machine
- Improvement of the design of the machine control systems
- Accurate prediction of the vibration of the system, required stiffness or thickness

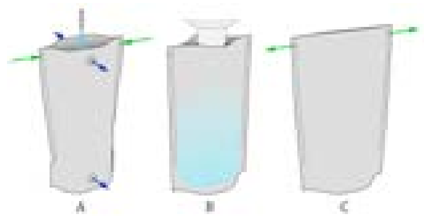
# Analyzing the filling process of a flexible pouch

**Product: Flexible pouch filled with liquid detergent**
**Purpose of Analysis: Investigating the effects of both design and process parameters to select the optimal machine configuration**

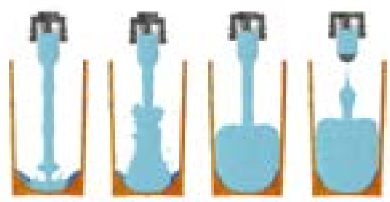
**Packaging companies expend significant effort to develop machines whose performance is expected to remain high and consistent even if the packaged goods, the packaging format, or the packaging material change. In the case study presented here, Coesia S.p.A., which is a leading multi-national packaging company headquartered in Italy, partnered with both EnginSoft S.p.A. and the University of Trento to simulate the full process through which a stand-up pouch is created, filled with liquid, and sealed in a Doypack® packaging machine. This challenging activity required the development of a multi-physics digital prototype of the machine-package-fluid system. In particular, the two-way coupling between multi flexible body dynamics and particle-based fluid dynamics was set up to properly replicate the interactions between fluid and a flexible pouch in dynamic conditions.**

## ◆ Process

① Most components are modeled as rigid bodies. (i.e., clamps, suction cups, nozzle, and shutter)
② The pouch is modeled as a deformable, flexible body capable of large deformation. (4-node, 6-DOF-per-node shell elements are used to represent the thin film.)
③ All stages of the process are simulated. (opening, filling, closing, and sloshing)
④ The modeling of the flexible pouch is fully automated using RecurDyn/ProcessNet, allowing the creation of multiple types of pouches in a short time.
⑤ A two-way-coupled co-simulation between RecurDyn and Particleworks is used to obtain a reliable representation of the Fluid-Structure Interaction. (FSI).
⑥ Experimental data is used for model validation. The optimal particle size and other numerical parameters have been set to balance model reliability and CPU time.



A. Opening, B. Filling, C. Closing



Filling process of the pouch

## ◆ Key Technologies for Analysis

- MFBD technology to handle the non-linearities due to both large displacements and extended frictional contacts
- Meshless particle-based CFD that is well suited to the free-surface flows such as injection or sloshing of liquids
- Seamless interface between RecurDyn and Particleworks for easy and accurate simulation of the Fluid-structure interaction (FSI)

## ◆ Toolkits

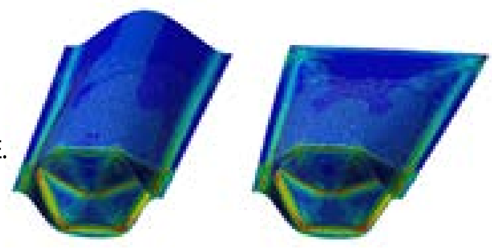
- RecurDyn/Professional
- RecurDyn/FFlex
- RecurDyn/ProcessNet
- Particleworks Interface

## ◆ Customer Challenges

- Understand the relationship between design and stability of the bottom gusset, which prevents the refolding of the pouch during operations.
- Identify the best design and process parameters through repetitive modeling and reasonably short simulations.
- Include the non-Newtonian behavior of the injected liquid, which affects the overall response of the pouch.
- Make sure that, even in dynamic conditions, the fluid level does not exceed a predefined limit to ensure that the sealing area remains clean during operations.
- Consider the interaction between fluids and flexible moving structures.

## ◆ Solutions

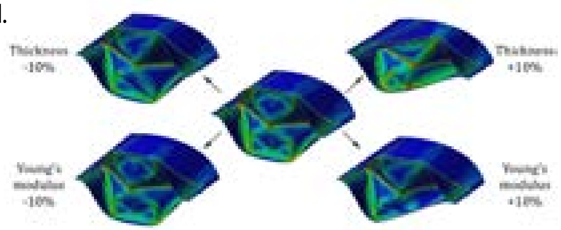
- RecurDyn MFBD technology is used that can simulate both rigid and flexible bodies in motion together.
- RecurDyn/ProcessNet provides the script to automate modeling and meshing for easy DOE.
- Co-simulation between RecurDyn and Particleworks can calculate the interaction between the fluid and flexible bodies.



Stress contour before (L) and after (R) closing

## ◆ Outcomes

- The stability and the opened/deformed shape of the pouch were reliably predicted.
- The simulation results provided additional guidance about the existing relationships between material properties, film thickness, and pouch design with the stability and the opening of the pouch itself.
- It has been possible to identify the proper thickness and the stiffness of the gusset of the pouch.
- The simulation results provided additional guidance about the motion laws and the performance of the machine.
- The digital model was able to provide some key information that could not be retrieved by performing classic physical testing.
- The entire simulation took about 10 hours in a regular workstation featuring a GPU. This allowed multiple investigations overnight without the need of HPC.




Parametric analysis results of the bottom gusset

## ◆ Other Applications

◀ MBD - CFD coupling

- Simulation of the conveyance of a fluid product in flexible packaging

For the detailed story

# Analysis based on human body modeling and wearable robot design

**Product: Wearable Robot**

**Analysis Goal: Establishment of a dynamic model of human body and wearable robot for checking the range of motion of the designed product and verifying the control model**

**Establishing a dynamic model of human body is essential in order to design dynamic model of wearable robot that a human can actually wear. Also, whether the robot can take all the necessary postures in various situations must be checked. This is done by estimating necessary torques of robot actuators according to the human body movements after attaching the wearable robot to the human body model and by checking the ROM (Range of Motion) of each joint. Lastly, the performance of the controller must be checked by co-simulation of the actuator control model and the dynamic model.**

## ◆ Process

① Acquisition of human body motion data, creation of the human body model through a human body program called 'Bio-motion', and inputting of motion data

② Implementation of a dynamic model after importing the previously generated human body model to RecurDyn

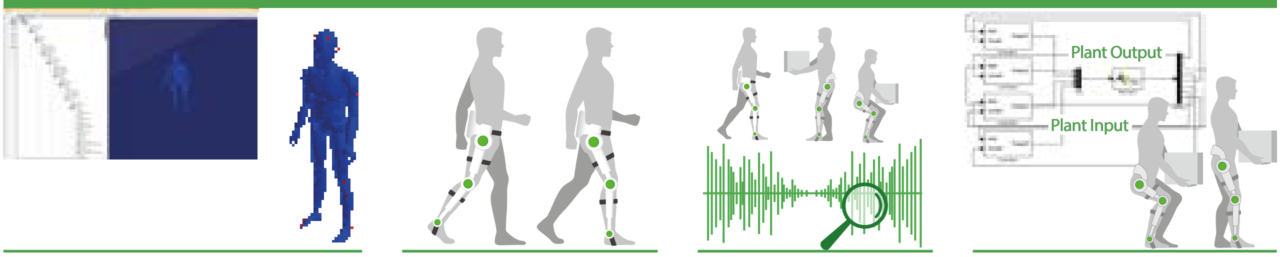
③ Attaching a wearable robot to a human body using bushings and execution of dynamic analysis of the human body movements → Acquisition of motion results of the wearable robot

④ Dynamic analysis after inputting of Ground Reaction Force (GRF) and the motion data of the wearable robot

⑤ Acquisition of required torque data of the wearable robot actuator and the range of motion (ROM) of the robot joints

⑥ Building a control model linkage using displacement and speed data of the actuator of the wearable robot and conducting co-simulation

**Creation of human body model (Biomotion Workbench)**




Creation of human body model | Attachment of a wearable robot to a human body | ROM and actuator torque analysis | Control model creation and conducting co-simulation

## ◆ Key Technologies for Analysis

- Creation of a dynamic model of human body using RecurDyn and Bio-motion
- Attachment of a wearable robot to a human body with a strap and dynamic modeling of the wearable robot
- ProcessNet customization to generate post-processing of the dynamic results and to apply measured data from human bodies as input to the RecurDyn model
- Co-simulation of the dynamic model and Simulink control model

## ◆ Toolkits

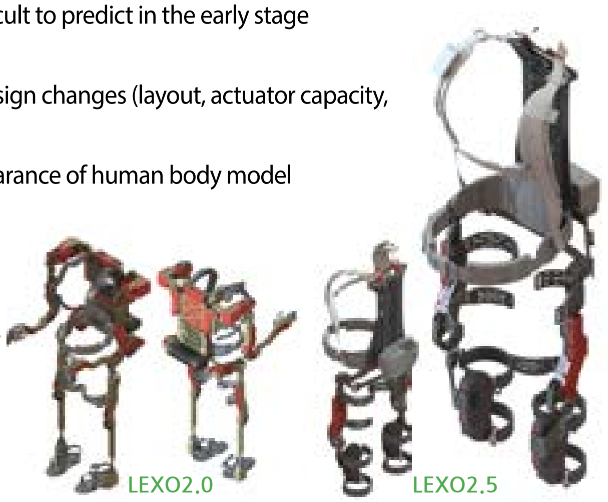
- RecurDyn/Professional
- RecurDyn x Simulink Co-simulation (RecurDyn/Control) or CoLink
- ProcessNet

## ◆ Customer Challenges

- Repair cost for product breakage during test process which is difficult to predict in the early stage
- Risk to a person wearing the prototype
- Excessive time and cost to repeat test processes every time the design changes (layout, actuator capacity, range of motion)
- Need for validation of wearable robot using various physical appearance of human body model

## ◆ Solutions

- Dynamic model creation including human body model to validate load torque of each joint
- Simulation using realistic and various human body models
- Cost reduction for prototype manufacturing through virtual validation of actuator capacity and range of motion




Wearable robot under developing using RecurDyn.
Courtesy of LIG Nex1.

## ◆ Outcomes

- After a human model which takes into consideration the torque actuator that is loaded on each joint was brought to RecurDyn, a dynamic model was established
- The torque and motion range of joints required for a robot for each assigned motion could be estimated and the motion range of actuator based on this estimation was proposed

## ◆ Other Applications

Muscle-power assisting robot for medical use

Wearable robot for military use

From the movie, Edge of Tomorrow.
This is an example image not related to RecurDyn.

Wearable robot for industrial use

◀ Analysis of a robot that can climb stairs

- Design of a controller in order to prevent a robot from falling down
- Determination of motor capacity required to operate a robot

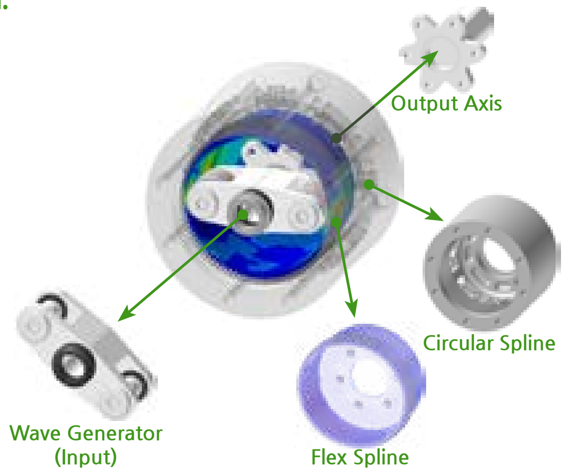
# Prediction of the performance of a strain wave gearing using a virtual model

**Product: Strain wave gearing**
**Analysis Goal: Performance evaluation for strain wave gearing design**

**Strain wave gearing, also known as harmonic gearing, is a kind of reduction gear that can achieve a very high reduction ratio in a very small and light structure. It is widely used in compact and high-precision products such as robots. A flexible gear (Flex Spline) is deformed into an elliptical shape by a rapidly rotating body (Wave Generator), causing its teeth to engage with the rigid, internal gear (Circular Spline). The rapid deformation, gear contact contact and significant inertial forces are difficult for traditional Finite Element Analysis (FEA) software to simulate. RecurDyn MFBD (Multi Flexible Body Dynamics) technology, which is precisely designed to simulate and analyze this kind of condition, was used to analyze this complex system.**

### ◆ Process

① Model the Circular Spline and the Wave Generator as rigid bodies.
② Model the Flex Spline as a flexible body using Full Flex, prestressed in its initial state.
③ Model contact between teeth of Flex Spline and Circular Spline using high-accuracy general purpose algorithm (Geo Contact).
④ Model contact between the Flex Spline and Wave Generator using optimized contact for rigid cylinder shapes (Geo Cylinder).




Courtesy of Trevor Glasheen

### ◆ Key Technologies for Analysis

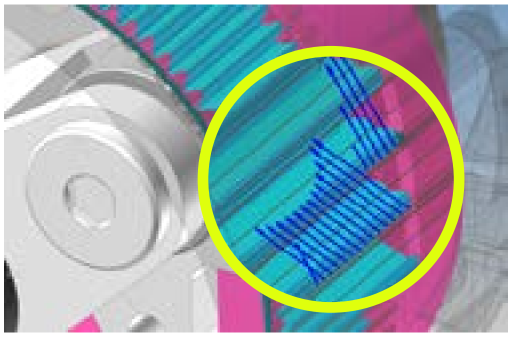
- MFBD solver that can accurately reproduce the high-speed motion and large deformation of the Flex Spline
- High-accuracy, low-computation contact algorithms
  - Contact between rigid bodies and flexible bodies
  - Efficient contact between a large number of gear teeth
  - Optimized contact for simple rigid geometry such as cylinders or spheres
- Visualization of contact force distribution and pressure due to contact between gear teeth

### ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

## ◆ Customer Challenges

- Evaluation of relationship between design parameters and performance
- Prediction of effect on vibration and transmission error due to dimensional differences within a given tolerance range
- Prediction of effect of applied load and operational speed on behavior of the Flex Spline
- Identifying the significance of the twist angle of the Flex Spline on performance
- Predicting the reaction force exerted on the Wave Generator



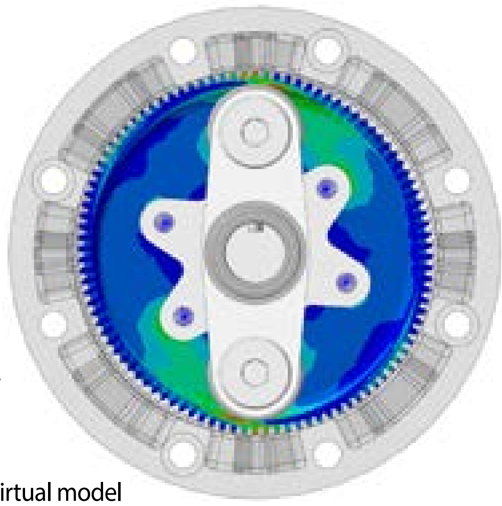
Visualization of contact force between gear teeth

## ◆ Solutions

- Modeling and Simulation time reduction through MFBD technology
- Reproduction of the Flex Spline behavior using nonlinear flexible body and contact algorithm
- Calculation of stresses in Flex Spline due to deformation and contact
- Simulation considering various design/operating conditions and tolerances

## ◆ Outcomes

- Evaluate the performance of the new tooth profile and reflect it in the design.
- Predict the efficiency and error for various design conditions and determine an optimal specification.
- Reduce time and cost through quantitative performance evaluation using a virtual model



Deformed shape and stress distribution of the Flex Spline

## ◆ Other Applications

◀ Transmission simulation using RecurDyn
- Dynamic simulation of transmission with multiple gears
- Analysis of gears' dynamic behavior when shifting gears

◀ Analysis of the reduction gear train which takes into consideration the viscosity of lubricating oil
- Visualization of the lubricating oil spray which was not possible until now
- The effect of the gear output according to the load of oil viscosity can be designed to be closer to reality.

# Virtual validation of an urban reconnaissance robot with 2 sets of tracks

**Product: Urban Reconnaissance Tracked Robotic Vehicle**
**Analysis Goal: Evaluation of stair climbing performance of the robot**

**A reconnaissance robot must be able to carry out missions under a variety of driving conditions, and missions in urban environments may have extreme mobility challenges such as climbing stairs.**
**One concept is a robot with sub-track assemblies in addition to the main track assemblies. While going up the stairs, the sub-track assemblies lay flat to provide a longer contact length. On landings, the sub-track assemblies are rotated up to shorten the required clearance for the robot and allow easy pivoting.**
**One military research group was evaluating the suitability of various types of robotic vehicles for an urban mission and wanting to be able to simulate the vehicle behavior. Modeling and simulating track assemblies with many bodies is not an easy task, but with the pre-defined track entities and assembly process automation in RecurDyn's special track toolkit, it was possible to build a virtual model and validate the stair climbing operation efficiently.**

## ◆ Process

① Fast, simple modeling of accurate, complex track model
② Specify contact parameters between track links and stairs.
③ Parts requiring user-defined motion controlled with simple, intuitive functions
④ Calculate the torques required for driving and climbing stairs used to determine appropriate motor capacity.

Courtesy of JPL Robotics

## ◆ Key Technologies for Analysis

- Specialized track user interface for fast modeling of track assemblies composed of numerous track links
- Fast contact algorithm that automatically detects contact between track links and the stairs
- Easy-to-use Function Expressions to represent the complex motion mathematically

Robotic vehicle using 2 sets of track assemblies

Reaction Forces at the sprocket joints can be visualized

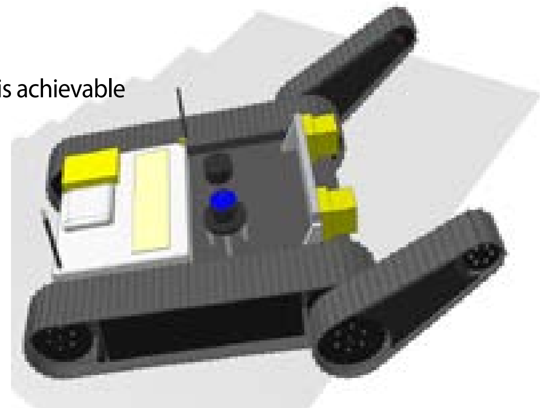
Model Animation

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/TrackHM

## ◆ Customer Challenges

• Fast validation of the new concept robot at an early stage to determine if mission is achievable
• Difficulty in modeling track assemblies with many track link bodies
• Complex contact conditions between the stairs and the track link bodies
• Need to simulate the complex motions of turning in place as well as climbing
• Difficulty in estimating the appropriate motor capacity to drive the robot



## ◆ Solutions

• Simulation of virtual model with high-fidelity track assemblies in various driving scenarios
• Fast and automatic contact detection algorithm specialized for track assemblies
• Quantitative estimation of the torque for the driving robot

Track assembly can be created easily using the track toolkit

## ◆ Outcomes

• Validation of the new design using a virtual model at an early stage
• Determination of motor capacity required for driving and climbing stairs and the energy consumption for a mission
• Definition of operational limits of the robot
• Simulation results provided guidance for potential design improvements

## ◆ Other Applications

◀ Analysis of a robot that can climb stairs
• Design of a controller in order to prevent a robot from falling down
• Determination of motor capacity required to operate a robot

◀ Short demo about how to use RecurDyn/TrackLM to create a tracked vehicle model easily
• RecurDyn/TrackLM (Track Low Mobility) gives the ability to simulate construction-style tracked vehicles.
• The toolkit supports the easy creation of sprockets, rollers, idlers and links.
• Also, graphical design of sprocket teeth profile and grouser of the track link is supported.

# Optimization of an elephant trunk robot manipulator

**Product: Elephant trunk robot manipulator**
**Purpose of Analysis: Optimize of the design of a flexible elephant trunk robot manipulator arm**

**An elephant trunk robot manipulator, an arm that mimics the behavior of an infinite degree of freedom elephant's trunk, was being developed. This robot manipulator is a set of disks attached at their centers to a flexible shaft, controlled by a set of cables that pass through the disks. The ends of the cables are attached directly to a motor. The arm has continuous motion and can be tailored for specific applications, for example, to access hazardous areas. To optimize the design of this flexible robotic arm, several parameters need to be investigated: tension in cable, force at the end of cable with respect to time, required force to actuate the mechanism, work volume of the robot.**

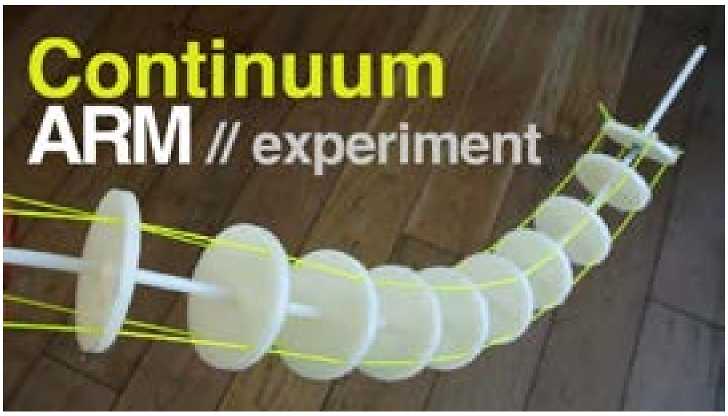
## ◆ Process

① Created the flexible elephant trunk robot manipulator that consists of trunk shaped body made up of circular discs, cables, a base, and a flexible shaft.
② Mathematically modeled the actuators and DC motor mounted at the base of the trunk using user-defined motion.
③ Investigated the range of motion that the robot manipulator can reach inside a working area.
④ Calculated and compared the strength of the cables during manipulation with different materials (Nylon, Teflon).
⑤ Calculated the loads experienced by the cables during operation.
⑥ Calculated the frictional loads experienced by the cable in contact with disc during operation.

## ◆ Key Technologies for Analysis

• Multibody dynamics that is specialized for mechanical modeling of many components: many discs, cables, base, shafts, and DC motor
• MFBD (FFlex) technology to represent the large deformation of the cables and predict their strength
• Contact, including friction, between flexible cables and rigid circular discs

Example of an elephant trunk manipulator unrelated to this research project




## ◆ Toolkits

• RecurDyn/Professional • RecurDyn/FFlex

## ◆ Customer Challenges

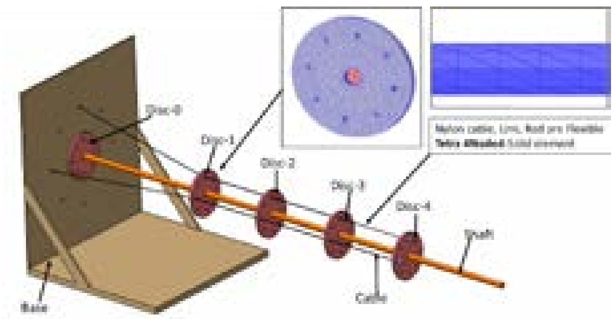
- Transient dynamic analysis is required to predict the motion of the manipulator.
- Cables experience nonlinear large deformation and frictional contact.
- Different cable materials, such as nylon or teflon, can affect the motion of the manipulator.
- The work volume of the robot manipulator must be identified.

## ◆ Solutions

- Modeling and dynamic simulation of the robot manipulator that consists of many components using professional multibody dynamics software
- Flexible multibody dynamics is necessary to calculate the behavior of the cable motion with large deformation.
- The trajectory of the robot manipulator could be examined through highly precise visualization and quantitative evaluation.
- A contact algorithm including friction between rigid bodies and flexible bodies

## ◆ Outcomes

- MFBD model accurately reproduced the dynamic behavior of the elephant trunk robot manipulator.
- MFBD model was used for optimization so that the maximum range of motion inside its work area could be reached.
- Accurate loads experienced by the cables were calculated.
- Appropriate motors and actuators could be selected.




## ◆ Other Applications

◀ A manufacturing robot arm simulation using RecurDyn

- You can see the vibration of the arm due to the flexibility of a part of the robot arm.

◀ Applications in Robotics Industry

- Applications
- Various case studies

# Robot Design Using Simulation

**Product: Multi-Axis Robot**
**Analysis Goal: Robot Controller Design and Component Specification Determination**

**There are many important aspects of industrial robot development, such as the motion controller, the stiffness of the components, vibration during operation, and the inertia ratio of the drive motors.**
**If a robot is designed using trial and error or experience, design problems can only be found after the prototype is complete. This can lead to a long development period and low product quality. Having the ability to evaluate a design through simulation before a prototype is made can dramatically reduce the cost of development.**
**ITRI, a technology research institute founded in 1973, used RecurDyn for virtual prototyping during the development of an articulated robot. Through RecurDyn, ITRI was able to simulate both the robot and its controller. This allowed for efficient design of both the controller and the various elements of the robot, such as motors, bearings, and reducers. Furthermore, RecurDyn's flexible body modeling was used to perform vibration analysis in various postures rapidly and efficiently, reducing development cost over traditional techniques.**

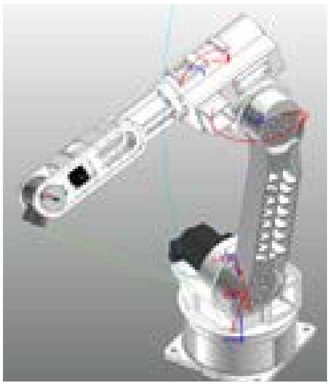
## ◆ Process

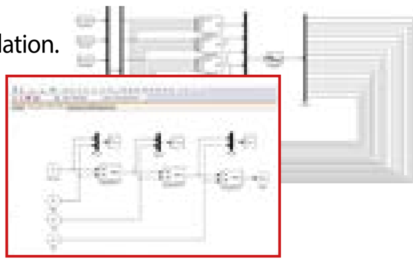
① Create a rigid body robot model that uses joints, bushings, couplers, beam forces, and other elements.
- Bolts were modeled using beam forces, which simulate quickly and allow for the stiffness of the bolt to be modeled accurately.
- Reducers were modeled using couplers that included bushing elements to represent the torsional rigidity.

② Model the robot controller using the built-in controller modeler CoLink and perform a co-simulation between RecurDyn and CoLink.

③ Convert specific bodies to flexible bodies, allowing the model to accurately vibrate.

④ Calculate the natural vibration modes for various postures during a time-domain simulation.





Controller design using RecurDyn model as a plant instead of a physical prototype

## ◆ Key Technologies for Analysis

- Inverse kinematics to predict the motion path of the robot
- Parametric modeling to easily tune the PID gains of the controller
- Modally reduced flexible body modeling that can include both normal modes and constraint modes for nodes that bearings are connected to
- The ability to perform eigenvalue analyses on the model at various points during a time-domain simulation

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

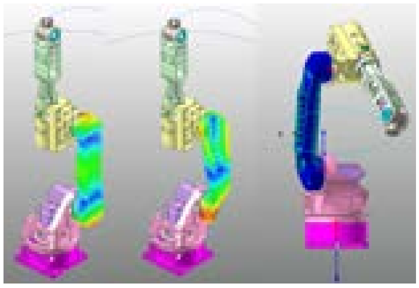
## ◆ Customer Challenges

- The need to quickly verify that a robot can perform the desired motion
- The need to quickly determine suitable specifications for bearings, motors, and reducers for a robot design
- Difficulty in predicting robot vibration characteristics that vary with robot posture
- Difficulty in designing a robot's motion controller without a physical prototype

## ◆ Solutions

- Prediction and verification of robot's range of motion using inverse kinematics
- Obtaining data such as torque and stiffness from the RecurDyn model
- Accurate prediction of the natural vibration modes of a robot using flexible bodies in the simulation model .

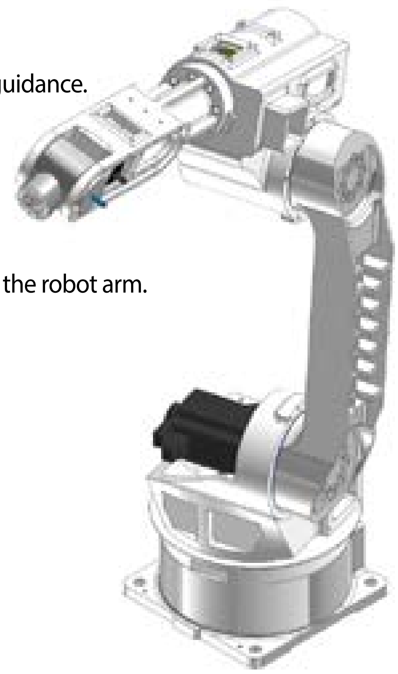
  Controller design using the RecurDyn model as a plant instead of a physical prototype



Natural vibration modes of the multi-axis robot can be analyzed with RecurDyn

## ◆ Outcomes

- The controller was designed quickly using a rigid body simulation model without any physical prototype.
- The data such as appropriate motor capacity and bearing stiffness necessary for the robot design was obtained through simulation
- Time and cost were reduced through quantitative evaluation of various possible designs.
- Visual simulation results such as natural vibration mode animation provide good design guidance.



## ◆ Other Applications

◀ A manufacturing robot arm simulation using RecurDyn

- You can see the vibration of the arm due to the flexibility of a part of the robot arm.

◀ Applications in Robotics Industry

- Applications
- Various case studies

# Examining many different circuit breaker concepts at an early development stage

**Product: Circuit Breaker**

**Purpose of Analysis: Identifying the influence of the tolerance of the locking pin on the closing performance of the circuit breaker**

**In the development of low-voltage switches, promising new concepts are compiled and the relative performance assessed using simulation and testing. To accelerate the new development of the mechanical switching devices, a lot of virtual testing is done with the help of different simulation tools. For many years, the Advanced Development Department of Siemens has used RecurDyn for the development and optimization of circuit breaker mechanisms.**

## ◆ Process

① Create initial design in CAD.
② Import initial design into RecurDyn as rigid bodies.
③ Simulate model to evaluate basic functionality.
④ Identify sensitive design parameters.
⑤ Vary parameters and determine optimal design configuration.
⑥ Identify bodies to convert to flexible bodies from rigid model force results.
⑦ Generate high accuracy and detailed results and prove reliability.

## ◆ Key Technologies for Analysis

- Extensive simulation capabilities for a wide range of fields and conditions
- Easy-to-use UI and fast solver for the circuit breaker system model simulation
- Multi Flexible Body Dynamics technology to analyze systems with flexible bodies

*"By using RecurDyn in the development of circuit breakers, we not only achieved improved product quality but also time savings thanks to RecurDyn's user friendliness."*
*- Johannes Greiner, Siemens AG*

*"We expect advanced software tools to be 100% reliable and robust. RecurDyn meets our high expectations; therefore we plan to increase our reliance on RecurDyn to handle all of our multi-body simulation needs."*
*Dr. Michael Anheuser, Siemens AG*

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

## ◆ Customer Challenges

- Need to reduce time to develop new mechanical switching devices
- Development iterations can cause the several months delay
- High speed and acceleration of circuit breaker body motion
- Risk that unidentified tolerances can cause the abnormal operation after a switch is manufactured
- Altering design parameters can affect complex interfaces and interactions between various subsystems.

## ◆ Solutions

- Significantly fewer development iterations using RecurDyn Simulation
- Ability to examine various product ideas using simulation
- Fast and robust Multi Flexible Body Dynamics solver to simulate extreme motion

**Devices with higher functionality require more complex assemblies, as shown here in the ACB switching mechanism.**

## ◆ Outcomes

- Identified the most critical design variables of the circuit mechanism.
- An optimal concept was identified early in the design process.
- Material cost saving of up to 50% were achieved.
- Loaded calculated by RecurDyn saved structural analysis engineers save time and material.

## ◆ Other Applications

◀ Circuit breaker simulation using RecurDyn

- The high-speed and precise motion of the circuit breaker can be accurately predicted with RecurDyn.

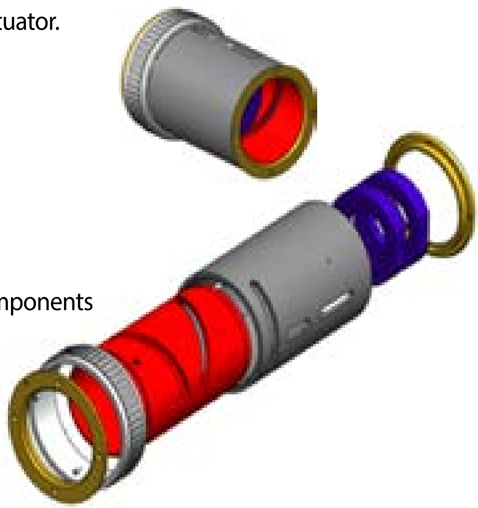
# Early validation of electro-optical instrument

**Product: High accuracy distance & gap measurement device**
**Purpose of Analysis: Validation of optical housing motion precision and minimization of the required torque**

An optical device is being designed that requires precise motion control and gap control. The device's optical magnification is adjusted through linear motion of the optical housing, which is controlled by rotary motions of the cam cylinders. This rotary motion is converted into linear movement through cam followers. RecurDyn was used to achieve smooth and precise magnification control. RecurDyn's multibody dynamics simulation was also used to perform stress and durability analysis and to minimize the required torque for the actuator.

## ◆ Process

① Created an MFBD model of the optical device.
② Minimized the torque for cam movement.
③ Traced the path/movement profile of cam cylinder and optical housing w.r.t angle of rotation.
④ Calculated the stresses on the cam cylinders as well as other parts in the assembly at different cam profiles.
⑤ Optimized the cam curve for smooth operation.
⑥ Predicted the required torque to determine the necessary motor capacity of actuator.



## ◆ Key Technologies for Analysis

- Multi Flexible Body Dynamics to properly calculate the stress on the moving components
- Easy-to-use contact algorithm to test various cam profiles
- Accurate MBD solver to predict the required torque to actuate the system

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

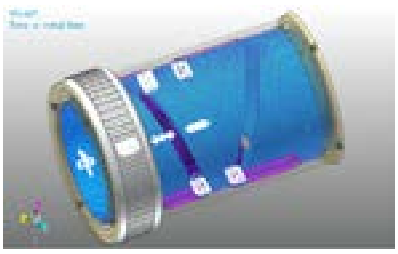
## ◆ Customer Challenges

- Early validation is needed to verify if a cam design can achieve the desired result.
- Stress generated on the various components varies depending on the cam profile.
- The required actuator torque needs to be minimized.
- The system involves the dynamics of various components including contacts, frictions.
- The cam follower movement must be smooth, without jerky movement, for precise motion.

## ◆ Solutions

- Dynamic model creation including cam-follower mechanism to validate the precise movement
- Fast and accurate simulation using powerful contact algorithm
- Flexible Multibody formulation to check the stress generated at different cam profiles
- Dynamic simulation to calculate the optimum torque required for the desired movement

## ◆ Outcomes



- The cam design with precise movement could be validated in early development stage.
- The stress generated from different cam profiles and follower regions was confirmed to be within the required limits.
- The driving torque was minimized.
- The simulation had good agreement with subsequent tests using physical prototypes.

## ◆ Other Applications

◀ Simulation of a cameras zoom lens mechanism

- The complex nonlinear interactions caused by contact and joints between the gears, pins, cam curve tubes, and other parts can be analyzed.

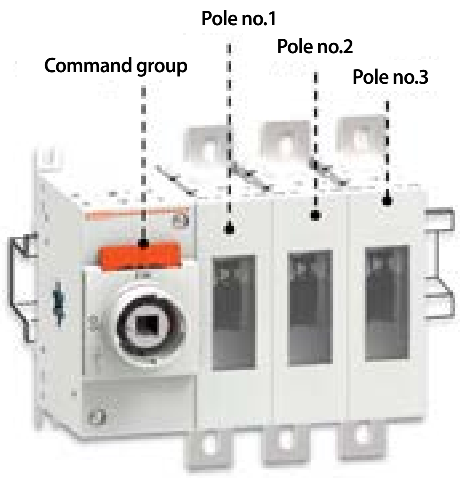
◀ Simulation of a circuit breaker

- The high-speed and precise motion of the circuit breaker
- Simulation of the various types of circuit breakers.

# Optimization of a switch disconnector through multi-body simulation

**Product: Switch Disconnector**
**Purpose of Analysis: Optimize the design to reduce arc generation**

**The most important aspect of a switch disconnector is the time taken to switch from the ON to the OFF configuration during an emergency maneuver. If it is too slow, an arc will be generated inside the switch that may damage the contacts and other nearby parts. Additionally, the overall design must deliver high robustness and sufficient durability. Lovato Electric S.p.A., Italy, introduced RecurDyn into its product design cycle to optimize the dynamics of its electromechanical devices, including the switch disconnectors. In addition to achieving the above-mentioned design goals, the company was able to reduce the number of physical prototypes and experimental tests, achieving a significant saving in the cost of the development.**



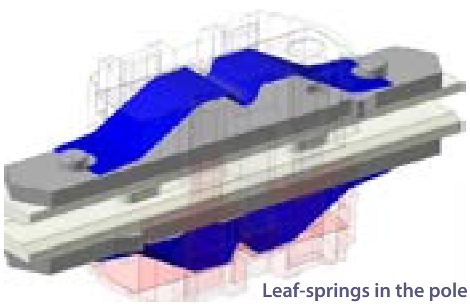

Switch Disconnector Architecture

## ◆ Process

① Creation of a leaf-spring subsystem (flexible body, including the mounting pre-stress)
② Virtual installation of multiple leaf-springs in the device
③ Assignment of parameters to control initial positioning uncertainty (clearances, tolerances)
④ Creation of a command group model that consists of 3 cams
⑤ Simulation of the entire system in different configurations to identify the optimal design

## ◆ Key Technologies for Analysis

- Full Flex technology to capture the large flexibility of leaf springs
- Geo-Contact technology to handle interactions between Full Flex bodies
- Subsystem modeling for maximum reusability of complex mechanisms
- Full Flex ability to create the deformed, pre-stressed initial states



Leaf-springs in the pole mechanism

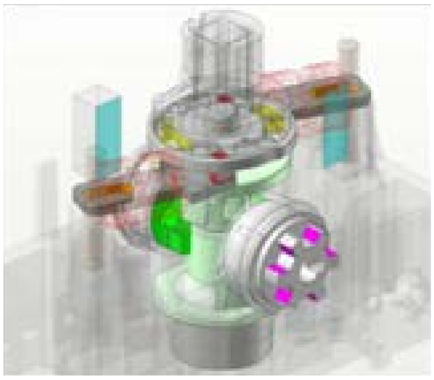
## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

A case from EnginSoft Newsletter #2, year 2019.
Courtesy of EnginSoft S.p.A., Italy (www.enginsoft.com).

## ◆ Customer Challenges

- High speed dynamics including flexible bodies and contacts which requires solver power and solver stability
- Detailed shapes and coupling clearances that affect performances must be taken into account with high accuracy.
- Presence of largely deformable bodies, nonlinear materials, and extended contacts: highly nonlinear problem
- CAD-embedded multibody (already in use) was not enough.



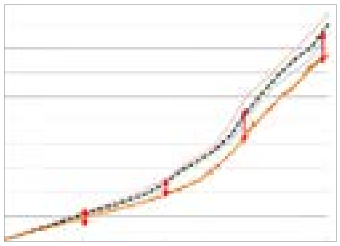
3 Cam-shafts in the mechanism

## ◆ Solutions

- The virtualization of the system was relatively easy due to the advanced GUI and the subsystem modeling capabilities of RecurDyn.
- Assembly (with clearances) was completed by using multiple and extended 3D General Contacts.
- Detailed Full Flex bodies allowed for the correct representation of leaf springs.
- High-performance and reliable MFBD solver succeeded in this high-demanding application.

## ◆ Outcomes

- The dynamics of the switch disconnector was accurately investigated.
- Many configurations were tested using simulation instead of building and testing multiple physical prototypes (time and cost saving).
- The optimal design was found and validated in a laboratory.



Validation of the leaf-springs subsystem

## ◆ Other Applications

◀ Simulation of a circuit breaker
- The high-speed and precise motion of the circuit breaker
- Simulation of the various types of circuit breakers

◀ High Speed Electrical Switching Mechanism at Siemens E&A

# Simulation of solar array stowage, deployment, and controlled operation

**Product: Solar array**
**Purpose of Analysis: Accurately predict the dynamics events in the life of a solar array, including spacecraft maneuvers**

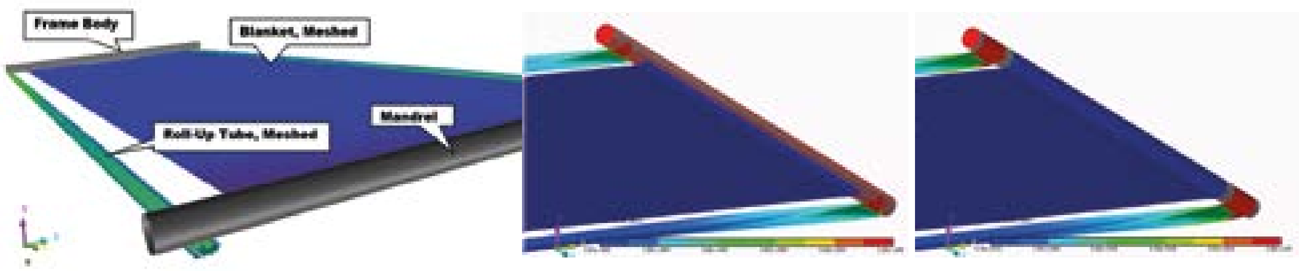
**Many recent spacecrafts require large, rollup solar arrays and need to undergo potentially significant maneuvers (or dynamic loading events) with the arrays deployed. There is an increased need to understand and control the nonlinear dynamics in the spacecraft system during such maneuvers. The nonlinear simulation of large structures can be challenging, therefore require multibody dynamics software, such as RecurDyn, that can model nonlinear flexible bodies and handle large motions. Another requirement is to be able to evaluate the effect of an active controller on the mechanical system.**

## ◆ Process

① 3 steps of simulation were used – Forming the Tube on the Mandrel, Rolling Up the Tube, and Deploying the Tube
② A customized add-on application that automates the previous 3 steps was developed to reduce the time to create a solar array model
③ Using the RecurDyn Extract function, the result of the previous step became the initial condition of the next step, in order to reduce the overall simulation time
④ Simulation, including the active controller, was performed to reduce vibration-induced loading in the solar array structure to minimize overall loads. Another result of using the controller was that the solar array panel acted as if it were stiffer (a very desirable result)

## ◆ Key Technologies for Analysis

- Multi Flexible Body Dynamics to properly represent the flexible bodies with large deformation and motion
- Uniform mesh was generated to minimize the numerical stress
- Integrated simulation of the mechanical system and the controller




Stress in slit tubes during and at the end of deployment.

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/CoLink
- RecurDyn/FFlex
- RecurDyn/ProcessNet

## ◆ Customer Challenges

- Physical testing of prototypes on earth with zero or micro-gravity can be difficult or impossible.
- New mission requirements call for the use of computationally efficient models of nonlinear flexible bodies undergoing large displacements.
- Need to simulate mechanical systems that include an active controller.
- Efficient simulation software needed to support repetitive simulations needed for parameter studies

## ◆ Solutions

- RecurDyn can model nonlinear flexible bodies and includes solution techniques that efficiently handle large motions in a mechanical assembly.
- RecurDyn provides a control simulation module, CoLink, which can model the controller with a block diagram and can simulate the controller together with the mechanical model using the RecurDyn integrated solver.
- RecurDyn/ProcessNet provides an integrated development environment to create a customized UI using C# or Visual Basic to automate tedious procedures.

## ◆ Outcomes

- Dynamic nonlinear behavior of the solar array was successfully reproduced.
- Rollup/deployment model development became much easier with the new solar array vertical application.


- Simulation results showed the dynamic behavior of the rollup solar array with nonlinear flexible bodies and active motion control options is better and safer.

## ◆ Other Applications

◀ Active Control of Solar Array Dynamics During Spacecraft Maneuvers,
Simulation of the Deployment of a Flexible Roll-Up Solar Array Using Multi-Body Dynamics Software,
- Brant A. Ross and Nelson Woo, at 3rd AIAA Spacecraft Structures Conference

◀ Simulation of aerospace industry
- Landing gear simulation
- Deployment simulation of Satellite Solar Panel
- Load calculation of the main rotor blade of a helicopter

# Simulation of removal and installation process of aircraft engine with winch system

**Product: Fighter Aircraft**
**Purpose of Analysis: Optimization of winch system for lowering and hoisting the engine during engine removal/installation process**

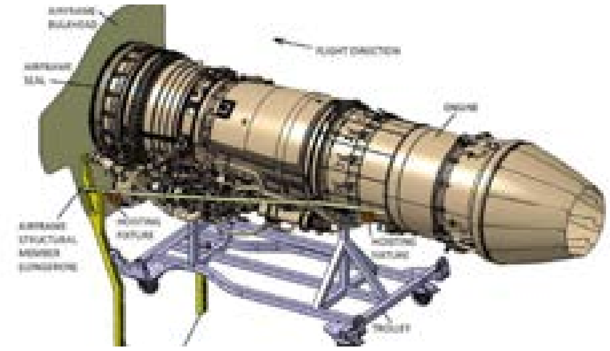
**An aircraft engine is housed in and integrated into an aircraft's rear fuselage. The engine weighs about 1500 kgs. Engine R/I (Removal/Installation) is a vital activity that needs to be carried out quickly with minimum manpower and tools. During this process, a winching system is used. It must ensure smooth engagement without any interference within the allowable loads. This process was simulated using RecurDyn to find the optimum geometry and design variables.**

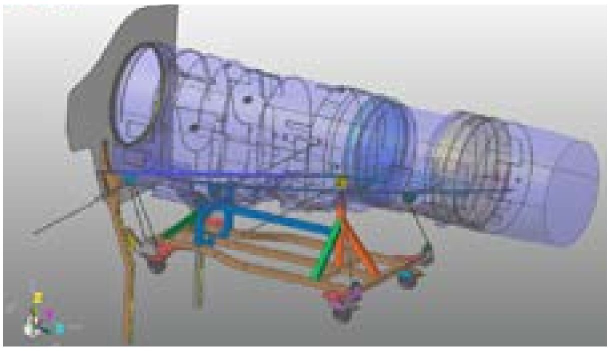
## ◆ Process

① The engine winching device and the engine assembly (CATIA model) were imported to RecurDyn.
② 2 types of models were created and simulated: One with a guide rail and one without a guide rail.
③ Optimization of the guide rail to define the ideal geometry to reduce loads and ensure smooth engagement of engine mount trunnions and lip seal
④ Finding the optimum location of the winch hooking fixture on the airframe
⑤ Finding the optimum forward inclination angle of the winch cable during engine pitch up/down
⑥ Decision making after comparing 2 types of design

## ◆ Key Technologies for Analysis

- Multibody Dynamics solver to predict the motion of the chain and pulley system of engine hoist
- Easy-to-use and accurate contact between rigid bodies and flexible bodies
- MFBD technology that uses flexible bodies to properly represent the deformation of moving components





Aircraft Engine with Winch System

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

## ◆ Customer Challenges

- Need to find the optimum mounting points without any interference on the fuselage for the engine hoist system
- Accurate prediction of the maximum load, including shock load, to ensure that it is within allowable range
- Smooth dismounting and mounting of the engine are required to avoid the damage and ensure safety.
- The winch system has complex contacts.
- Many components, such as cables, experience large, nonlinear deformation.
- Needs extensive testing or simulation to ensure reliability in actual operating conditions.

## ◆ Solutions

- A fast and robust dynamic solver was used to find the optimum design parameters, including mounting points, inclination angle, and geometry of the guide rail
- Fast and accurate simulation using powerful contact algorithms
- Accurate prediction of the deformation, vibration, and loads using high-fidelity multi flexible body dynamics

## ◆ Outcomes

- Optimum results of the winch system
- Optimum design that reduces the load on the guide rail
- Alternative winching mechanism that eliminated the guide rail, which is a simpler system for field maintenance

## ◆ Other Applications

◀ Analysis of structural oscillations on linear handling axes

Establishing the digital twin model of the linear handling axes to analyze its structural oscillations

◀ Landing Gear model

RecurDyn can be very beneficial for analyzing the design of the components of the landing gear of an airplane. The forces acting on such a component can be accurately predicted in a simulation of the multibody dynamics of the landing gear system.

# Vibration characteristics of washing machine dehydration and effects of vibration reduction devices

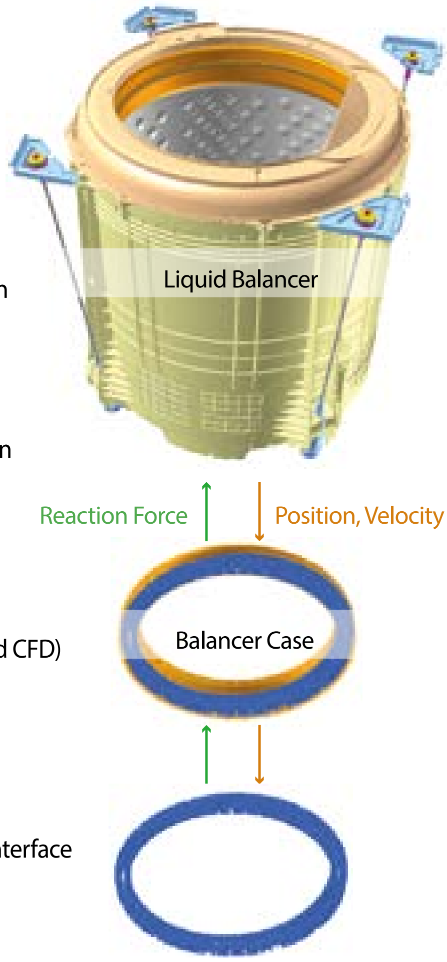
**Product: Top Loading Washing Machine**
**Purpose of Analysis: Reproduction of vibration characteristics of a washing machine and comparison of characteristics of vibration reduction devices (suspension, fluid balancer)**

Washing machines generate large vibrations and noise when washing and spin-drying. These vibrations and noise are crucial factors in washing machine development because they have a significant influence on customer satisfaction. Various vibration reduction devices such as suspension and fluid balancers are used in washing machines.

A virtual washing machine model with 4 suspension elements was created and simulated in RecurDyn to analyze its vibration characteristics. The effects of the suspension types and the structural shape of fluid balancer was compared. The simulation accurately reproduced the vibration phenomenon of washing machine, and the results were in good agreement with physical tests. This virtual washing machine model is expected to be used for improving washing machine design in virtual environments and solving problems in the future.

## ◆ Process

① Precise modeling of the dynamics of suspension used in washing machines
② Correlation between the physical tests and simulation of the suspension
③ Simulation of entire washing machine and analysis of its vibration characteristics
④ Modeling a fluid balancer through co-simulation with CFD
⑤ Investigation of the effects of washing machine vibration reduction devices such as suspension and fluid balancers and the mechanisms of vibration generation




## ◆ Key Technologies for Analysis

- Mathematical modeling of nonlinear characteristics for washing machine suspension (friction, pneumatic, viscoelasticity)
- Efficient modeling and optimization using parametric modeling
- Reduction of modeling time using subsystems
- Particle-based CFD using Particleworks
- Integrated RecurDyn and Particleworks simulation (co-simulation between MBD and CFD)
- Post-processing for vibration characteristics analysis (FFT, Campbell Diagram, etc.)

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/AutoDesign
- Particleworks Interface

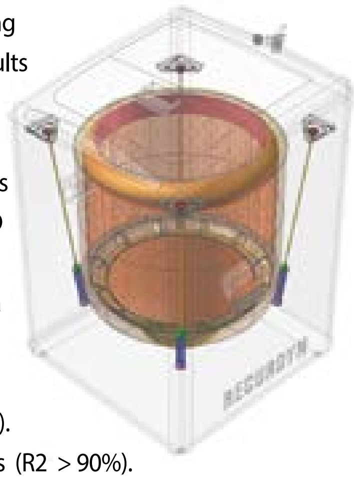
LG Electronics

## ◆ Customer Challenges

- An accurate simulation model for vibration evaluation
- Nonlinear characteristics of suspension
- Identification of vibration during dehydration
- Demand for both reducing modeling and analysis time
- Vibration evaluation for various weights and eccentric conditions of laundry
- Simulation technologies for washing machine vibration evaluation that include the effects of fluid balancers are required.

## ◆ Solutions

- Mathematical representation of nonlinear various suspension characteristics using Function Expressions
- Model simplification and time saving through suspension subsystem and parametric modeling
- Improvement of analysis accuracy through comparison between actual tests and analysis results for nonlinear characteristics of suspension
- Obtaining optimal values for suspension model parameters using AutoDesign
- Implementation of washing machine model for vibration analysis reflecting various conditions
- Vibration evaluation including a fluid balancer through co-simulation with particle-based CFD
- Validation of simulation results with vibration measurements using laser sensors
- Validation of simulation results of fluid balancer with measurements using high speed camera




## ◆ Outcomes

- Simulation results of a suspension model matched with measurement results well (error < 6%).
- Simulation results of dehydration vibration were in good agreement with experimental results (R2 > 90%).
- The vibration characteristics and mechanism of the washing machine for various suspension types were identified.
- The vibration mechanism of washing machine according to the type and structural shape of the fluid balancer was identified and the fluid behavior could be visualized
- Reduction of analysis time through model optimization (more than 40% compared to existing models)

## ◆ Other Applications

◀ Automatic washing machine simulation
- Vibration reduction simulation using 4 suspension elements

◀ Washing machine simulation using RecurDyn and Particleworks
- Co-simulation of multibody dynamics model and CFD model
- Laundry modeling using flexible bodies in RecurDyn

◀ Modeling and vibration control of a front-load washing machine using MR fluid damper
- Verification of bearing model between tub and drum of a front-load washing machine
- Simulation of suspension consisting of two springs and MR damper

# Using a calibrated multi-body model to predict the NVH exciting loads in a fridge compressor

**Product: Household compressor for use in domestic fridges**
**Purpose of Analysis: Automation of the calibration between simulation result and experimental data to produce a reliable virtual model**

**A multi-body approach is very suitable for calculating a generic vibrating structure's excitation loads, which can be later used to perform Vibro-Acoustic analyses. For the outputs to be reliable, the unknown / imprecise / unmeasurable parameters of the multi-body model need to be finely tuned at the beginning of the process. This tuning is the so-called calibration process, which ends when a model's outputs match the corresponding signals measured in a laboratory. The calibration process is usually very time consuming and complex to perform. The best way to accomplish this task is connecting the parameterized model to an automatic multi-objective optimizer. In the following application, which is a compressor for refrigerators, the RecurDyn model was adjusted by the algorithms of modeFRONTIER until the simulated accelerations matched the measured ones.**

## ◆ Process

① Modeling of compressor using rigid bodies only (which in this case had no impact on result quality)
② Modeling of support springs using Full Flex (beam elements)
③ Definition of unknown / variable parameters such as damping coefficients, inertial properties
④ Definition of scalar indices representing the mismatch between model and physical prototypes
⑤ Connection of modeFRONTIER to RecurDyn (via scripts)
⑥ Automatic execution of hundreds of simulations.
(modeFRONTIER understands the model at each loop and drives the model towards a better matching of accelerations)
⑦ Excitation loads are extracted from the most calibrated model.

RECURDYN
X
modeFRONTIER

## ◆ Key Technologies for Analysis

- Full Flex technology to represent the soft helix springs supporting the motor-pump assembly
- Parameterization of inertial and stiffness properties
- Batch capabilities of RecurDyn to enable the connection with modeFRONTIER

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex
- modeFRONTIER (from www.esteco.com)

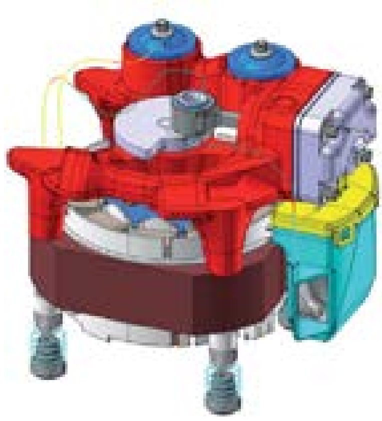
A case from EnginSoft Newsletter #2, year 2018.
Courtesy of EnginSoft S.p.A., Italy (www.enginsoft.com).

## ◆ Customer Challenges

- Development of a super silent household compressor
- Need for a reliable virtual model to predict NVH response
- Understanding the highly-nonlinear relationships between spring properties and response
- Finding the exciting loads to be used in an acoustics simulation

## ◆ Solutions

- RecurDyn's Full Flex enabled the accurate representation of the large deformation of the springs and their nonlinear behavior.
- The model was finely calibrated by coupling RecurDyn with the modeFRONTIER multi-objective optimizer.
- The calibrated model returned reliable values for the internal loads exciting the compressor's case.



Household compressor used in domestic refrigerators

## ◆ Outcomes

- Calibration with experimental data was performed through an automated process.
- It was revealed that multi flexible body dynamics is suitable for NVH analysis in a wide range of frequencies.
- Multi flexible body dynamics enabled acoustics analysis.

## ◆ Other Applications

◀ Vibration characteristics of washing machine dehydration and effects of vibration reduction devices

- Identifying the vibration characteristics and mechanism of the washing machine for various suspension types
- Reduction of analysis time through model optimization

◀ Washing machine simulation using RecurDyn and Particleworks

- Co-simulation of multibody dynamics model and CFD model
- Laundry modeling using flexible bodies in RecurDyn

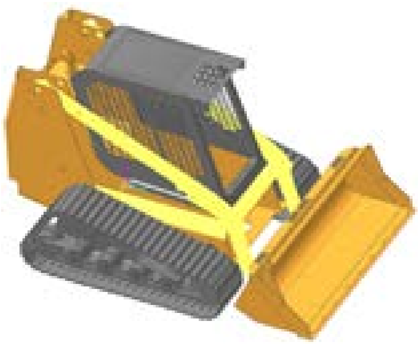
# Cost savings through compact track loader simulation

**Product: Compact Track Loader**
**Purpose of Analysis: Improvement of the durability of the track loader**

**CASE NEW HOLLAND (CNH), a leading agricultural and construction equipment company, is increasing its motion simulation capabilities as its product designs evolve. One example is the design of compact track loaders that were developed to provide increased traction and reduced ground pressure as compared to traditional skid-steer loaders with tires. Since the simulation results were obtained more quickly than physical testing, CNH could focus on the areas of the design to improve the performance of the product. Through simulation, CNH could achieve system level improvements as well as component level improvements and consequently the product durability.**

## ◆ Process

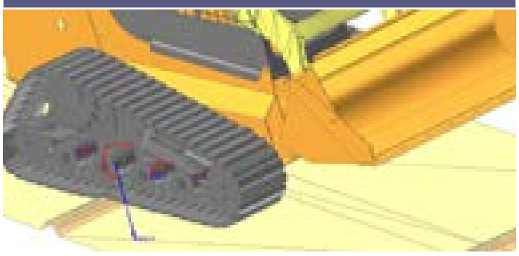
① Dynamic modeling of the track system
② Comparison between the actual test and analysis results, as well as detailed parameter tuning
③ Virtual simulation to generate feasible outputs that are not available or verified from physical testing
④ Durability analysis using the load data and the component stress during worst-case conditions



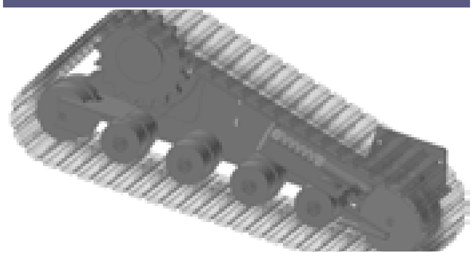
## ◆ Key Technologies for Analysis

- Specialized track UI for various track components including rollers and idlers
- Automatic creation of the complex track assembly
- Reduction of modeling time using subsystem
- Force/Torque display to visually verify the load applied to the components

Force/Torque applied to rollers and idlers are displayed.



Efficient modeling using subsystem



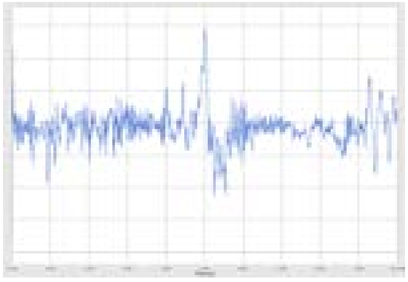
Simulation Animation

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/TrackLM

## ◆ Customer Challenges

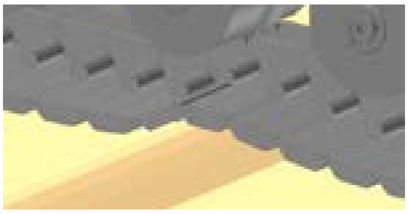
- Development of a compact track loader with good durability
- The flexible behavior of the band track must be taken into account.
- The contact between the track, idlers and track rollers must be considered.
- Preventing de-tracking when the loader is operating along the side of a slope



Track tension can be quantitatively reviewed

## ◆ Solutions

- Fast modeling of the 3D dynamic model using specialized track UI
- Driving simulation of the track loader for various road conditions
- Quantitative evaluation of the load applied to the front and rear idlers and other components under various conditions
- Change of the placements of roadwheels in the track assembly, and center of mass location for the vehicle
- Change of the track tension to prevent de-tracking
- Additional material in locations of high stress



Accurate calculation of the track assembly

## ◆ Outcomes

- Replacing physical testing which saves a large amount of money and time
- Improved product durability from design changes based on simulation results
- Designed for improved product performance

*" RecurDyn's computational speed and process automation for track systems allowed us to develop accurate simulations of our compact track loaders that would have not otherwise been practical. Although we are continuing to gather data, we are confident that we are reducing our engineering costs by at least two dollars for every dollar that we invest in simulation."*
*- Kezhun Li,*
*manager of Digital Prototyping and Simulation at CNH*

## ◆ Other Applications

◀ Simulation of construction machinery using RecurDyn

- Evaluate driving stability and undercarriage durability
- Improve arm and upper frame durability
- Predict track link damage

*"It would have taken a large investment of money and time to obtain the needed data through physical tests. The simulation results were obtained quickly and helped us focus on the areas of the design where we could improve the performance in the field."*
*- Adam Ewing, CNH Project Engineer*

◀ Short demo about how to use RecurDyn/TrackLM to create a tracked vehicle model easily

- RecurDyn/TrackLM (Track Low Mobility) gives the ability to simulate construction-style tracked vehicles.
- The toolkit supports the easy creation of sprockets, rollers, idlers and links.
- Also, graphical design of sprocket teeth profile and grouser of the track link is supported.

# Virtual test development of tractor rear roll bar ROPS using MFBD

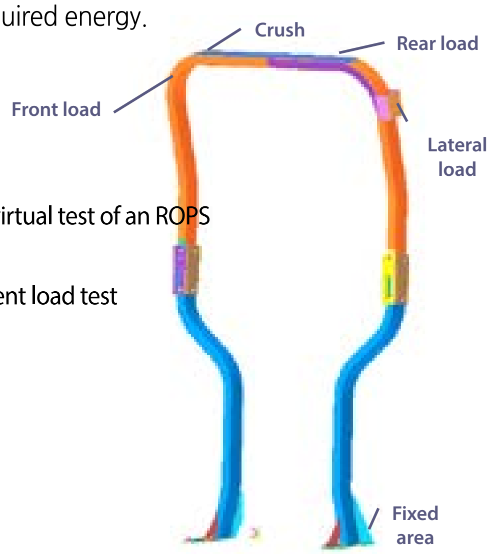
Product: Tractor ROPS (Roll-Over Protective Structure)
Purpose of Analysis: Implementation of the virtual test of ROPS using MFBD

A ROPS (Roll-Over Protective Structure) is a structure to protect the driver from injury when a tractor or heavy equipment rolls over. A ROPS must be able to sufficiently absorb the impact with the ground and provide a safe space for the driver when the vehicle is overturned, The test procedure for evaluating the safety of such ROPS is prescribed in OECD Codes in the Agricultural Mechanization Promotion Act. In this project, a virtual ROPS test was implemented using RecurDyn's implicit solver-based MFBD toolkit. After that, the convergence and error of the solution were evaluated by comparing the results with static nonlinear analysis.

## ◆ Process

① Created an MBD model including a model of the driver safety zone, ROPS, and load actuator.
② Created a flexible model of the ROPS. (modeled with shell elements because it is long and thin.)
- Geo Surface Contact was used between the rigid load actuator and ROPS modeled using FFlex to minimize oscillations in contact.
- Modeled welds with FDR (RBE2) elements considering the characteristics of mid-surface type shell elements, which have difficulty in sharing nodes.

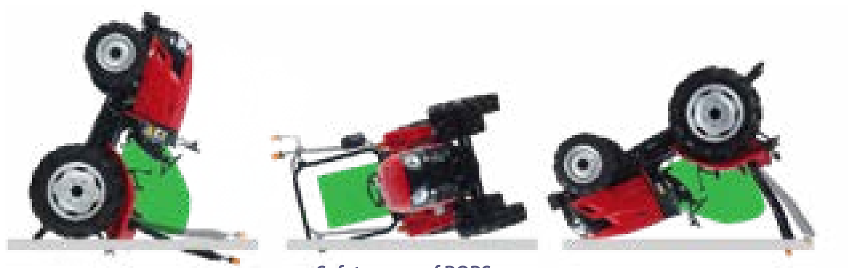
③ Implemented a consecutive displacement load test.
④ Evaluated and compared the maximum displacements that satisfied the required energy.



Test model of ROPS

## ◆ Key Technologies for Analysis

- Multi Flexible Body Dynamics (MFBD) technology that can accurately reproduce the virtual test of an ROPS
- FDR (RBE2) that can model welding of mid-surface type FE elements
- Scenario Analysis and Contact On/Off control to implement a consecutive displacement load test


Safety zone of ROPS

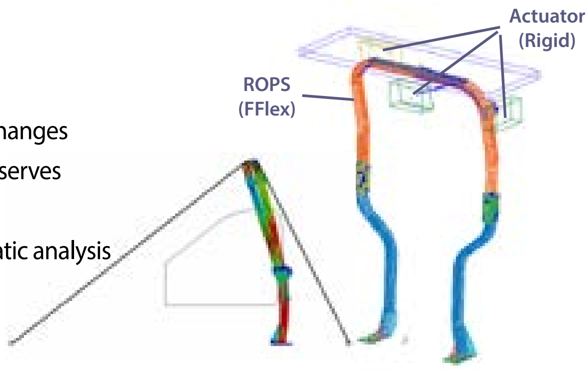
## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

This project was presented at 2021 RecurDyn User Conference (Korean)

## ◆ Customer Challenges

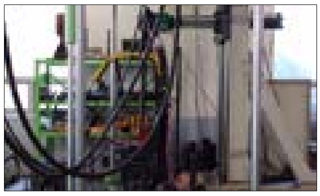
- Loss of time and cost from preparing samples for physical tests
- Need for evaluation of safety in advance for various possible design changes
- Need to implement a consecutive load control methodology that preserves residual stresses
- Simpler contact definition and higher convergence than nonlinear static analysis
- Need for simulation time reduction



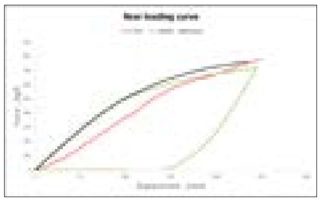

ROPS simulation model

## ◆ Solutions

- Implementation of a simulation model using RecurDyn MFBD technology that can replace the physical test
- Reduction of simulation time by creating a shell element flexible body from the mid-surface geometry from a CAD model
- Use of multi-linear isotropic hardening that allows for large deformation of structures and their plastic material nonlinearities
- Safety zone violation check at each load stage while the plastic deformation was preserved using the consecutive analysis
  - Use of enabling and disabling contact through Scenario analysis for the consecutive analysis

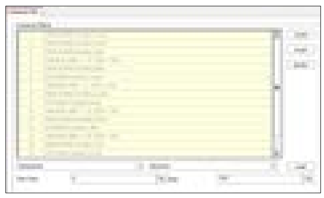


ROPS TEST



ROPS displacement - load

## ◆ Outcomes



- An ROPS nonlinear simulation model was developed that utilizes RecurDyn's implicit MFBD solver.
- It was confirmed that the simulated maximum displacement error was similar to physical test results.
- Higher solution convergence was obtained with a relatively simple contact definition than using static nonlinear analysis.
- The same simulation method as the physical test environment was implemented by applying the displacement control method using the Scenario analysis.

## ◆ Other Applications

◀ Cosimulation of Tractor mid-mower

- Analyzing the dynamic behavior of a tractor with a mid-mower using RecurDyn and particle method

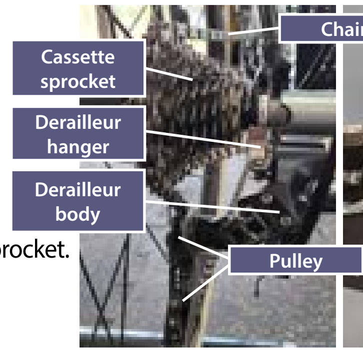
# Automated creation and simulation of the bicycle transmission model

Product: Bicycle transmission system
Analysis Goal: Automation of the repetitive process of bicycle transmission modeling to evaluate the various designs efficiently

Bicycle transmission performance can be evaluated from two perspectives. One emotional, such as how smoothly and precisely a shift occurs. The other relates to energy, such as how little human power is required to shift and how small the energy loss is during the process of shifting.
A bicycle chain has many links. Accurately simulating a bicycle transmission requires precise calculation of contact between the sprockets and all of the chain links. Each transmission simulation model requires many elements to be created, which would be time-consuming if performed by hand. In particular, a sophisticated contact definition for each chain link is needed that can reduce simulation time, which is also time-consuming. Furthermore, every change in any component design requires the creation of a new simulation model. RecurDyn was chosen to simulate these bicycle transmissions because it allows for scripting using the C# language to automate many aspects of model creation. This allowed for a large number of models to be created rapidly, and furthermore, through optimized contact modeling, reduced the simulation time of each model as well. With this customization, various shapes of the chain link, the installation angle of the sprocket, and the tolerance between the chain roller and the pin were able to be efficiently modeled, simulated, and analyzed.

## ◆ Process

① Imported CAD data of all parts of bicycle transmission, including chain links.
② Used a ProcessNet script written in C# to automate the creation of the bushing forces, the definition of the contact surfaces on the chain links, and the creation of the contact between the sprockets and chain links.
③ Evaluated the performance for various angles of the cassette sprocket.
④ Evaluated the performance for various chain link shapes.



Various parts of bicycle drivetrain

Machined surface of chain link

## ◆ Key Technologies for Analysis

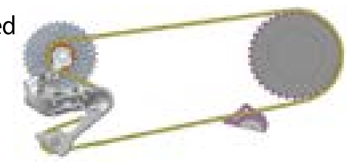
- MBD solver and contact algorithm that can accurately simulate a large number of bodies and contacts between those bodies (109 chain links and other bodies, 648 contacts)
- Built-in customization scripting to automate repetitive operations such as creation and modification of many objects
- Bushing force model that can properly model the characteristics of a chain
- Parallel processing technology for high-speed simulation

## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/ProcessNet

## ◆ Customer Challenges

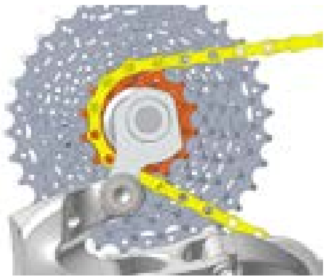
- Difficulty in making prototypes whenever the geometric shape of the components is changed
- Need for data that is difficult to measure with physical tests
- Need to create another model for every modification of the chain link shape
- Possibility of the long simulation time because of the large number of bodies and contacts



Simulation model
of the bicycle drivetrain

## ◆ Solutions

- ProcesseNet scripting customization using C# to automate tasks that need to be repeated whenever the chain link and sprocket shapes are changed
- Reduction of simulation time by using the specific surface of the chain link for contact, not the entire surface
- An MFBD solver that efficiently utilizes parallel processing for faster simulation (used 8 cores.)



The chain wrapped around the sprocket

## ◆ Outcomes

- The bicycle transmission model was created rapidly using the built-in customization tools for automation.
- The relationship between the derailleur position, the install angle of the sprocket, the shape of the chain link, and the time to complete the shift were successfully identified.
- Verified the possibility and ease with which the chain can come off.
- The contact force between the chain link and the other parts was obtained.
- The force and torque required to execute a gear shift were identified.

Automation program made with ProcessNet (C#)

## ◆ Other Applications

◀ Shift operation using bicycle transmission

◀ Bicycle simulation using RecurDyn

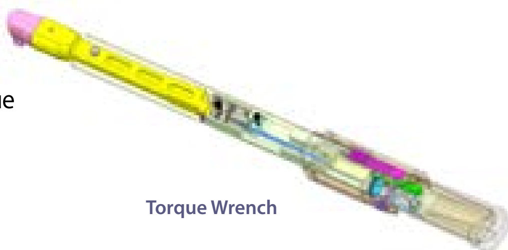
# Improved torque wrench design and the precision of its torque indicator

**Product: Torque Wrench**
**Analysis Goal: Design a precise torque scale that captures the nonlinear behavior of the torque wrench**

A torque wrench is a wrench that allows the user to apply a specific amount of torque to fasteners like bolts and nuts. Some torque wrenches have torque-limiting switches that prevent the wrench from applying more than a user-specified amount of torque. Using experimentation to verify that a torque-limiting switch accurately meets its specifications is difficult. Furthermore, designing it using physical experimentation is costly and time-consuming. In this case study, an existing torque wrench design was modified, which required that the wrench's torque indicator be modified as well. Simulation was used to redesign the indicator and improve its accuracy. Therefore, the indicator was modified using simulation instead of experiment. Because the applied torque is nonlinear due to dynamic behavior, deformation, and contact between various parts, it could not be reproduced with traditional FEA software. Therefore, RecurDyn, a Flexible Multi Body Dynamics (MFBD) software, was used to design the torque wrench, and it was possible to design an accurate torque wrench with precise torque indicator.

## ◆ Process

① Modeled the torque wrench's primary coil spring using flexible beam elements and all other parts using rigid bodies.
② Defined contacts between the flexible beam and rigid bodies.
③ Tested various coil diameters and material properties for the primary spring.
④ Determined the precise configuration of the torque indicator through the torque values obtained from the simulations.

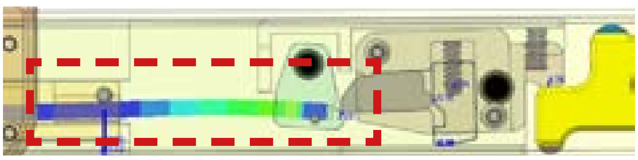

Torque Wrench

## ◆ Key Technologies for Analysis

- MFBD modeling that allows for simultaneous use of rigid and flexible bodies
- Contact between rigid bodies and flexible bodies
- Efficient parametric modeling for testing various beam diameters and material properties
- Robust solver technology that accurately reproduces the nonlinear behavior of the torque wrench

Validation via Sample Mechanism is very time consuming.

RecurDyn accurately predicted the nonlinear effects of the beam.
(Representation of the primary coil spring)



## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

## ◆ Customer Challenges

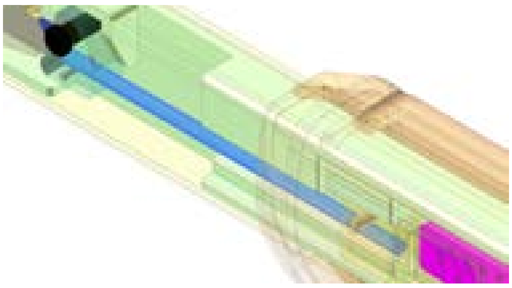
- For increased torque range, need to change spring free length and coil diameter
- Nonlinear motion needed to be evaluated to accurately predict the torque
- Need to improve the design with reasonable time and cost

## ◆ Solutions

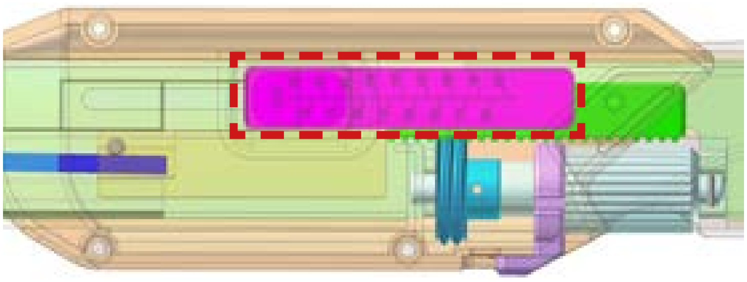
- Precise torque calculation using MFBD technology which can simulate systems with both rigid and flexible bodies that make contact with each other.
- Modeling simplification and time-saving through beam and parametric modeling
- Simulation of various designs using an intuitive user interface

## ◆ Outcomes

- RecurDyn was able to accurately recreate the behavior of the existing design.
- RecurDyn validated the nonlinear behavior and created confidence in using non-uniform torque scale on the indicator.
- Time and cost reduction through quantitative evaluation of various possible designs
- Simulation results provided additional guidance for further design improvements for the torque wrench.



Circular beam mesh was used to model a coil spring



Torque indicator: The new design required a non-uniform scale.

## ◆ Other Applications

◀ Analyzing the design of locking plier using MBD for ANSYS (RecurDyn)

# Application of flexible multibody system dynamics to multi-rope friction hoisting design

**Product: Mine hoist**

**Analysis Goal: Evaluate the tension and dynamic stress of a multi-rope friction hoisting system**

**A multi-rope friction hoist for deep mine lifting consists of a drum, steel hoisting ropes, conveyances fixed at end of the hoisting ropes, tail ropes connected between the 2 conveyances, and possibly sheaves. The hoisting ropes and the tail ropes form a balanced, catenary-shaped loop that hangs from the drum or potentially from the sheaves. The hoisting ropes are driven by the rotation of the drum. The ropes pass through grooves lined with high-friction material in the surface of the drum. The lifting height, the loads, and the operational speeds can be high. The lengths of the hoisting cables vary with time, and lateral oscillations of the ropes can be very problematic for stable operation. The tension and dynamic stress in key bodies of the multi-rope friction hoisting are important for the judgement of running stability. These were evaluated using multi flexible body dynamics in RecurDyn.**

## ◆ Process

① Created an MFBD model that consists of a rotating drum, a fixed headframe, two sheaves with identical kinematics structure, and two conveyances.

② Set the density of all components with steel to 7800 kg/m3 for simplicity.

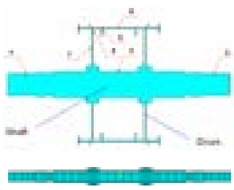
③ Set the static and dynamic friction coefficients of the joints to 0.1 and 0.05, respectively.

④ Conveyances modeled as simple solid bodies.

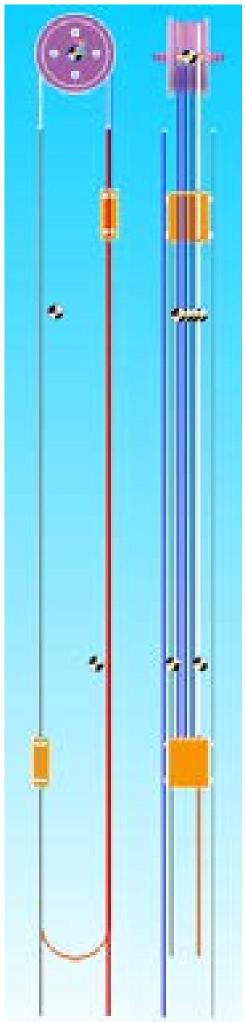
⑤ Ran simulations with 0-, 15-, and 34-ton loads.

⑥ Compared results with experimental tests.

RecurDyn simulation model



Strain gauge position in field test



## ◆ Key Technologies for Analysis

- Joints between components to accurately reproduce the pitch and roll behavior of a 3-DOF vibration tester
- Kinematic model to apply prescribed vibration independent of the stack mass
- Modeling technique to mimic collapse prevention film

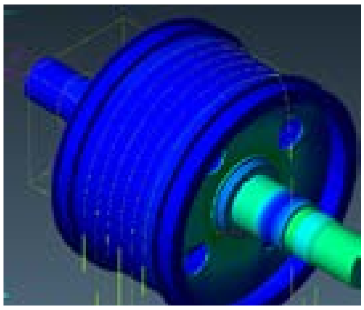
## ◆ Toolkits

- RecurDyn/Professional
- RecurDyn/FFlex

Innovation Scientists and Technicians
Troop Construction Project of Henan Province, China

## ◆ Customer Challenges

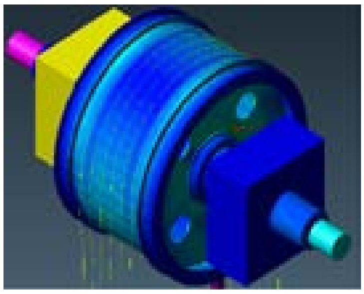
- Operating requirements: heavy loads, high lifting speed, and high lifting height
- Running stability: vibration characteristic of friction hoisting
- Safety and high efficiency: drive characteristics of friction hoisting
- Safety and economics: calculating fatigue in friction hoisting system
- Effect of cable pay-out/reel-in rates on cable stress and elongation
- Cable dynamics and stability



stress contour at 0.5s

## ◆ Solutions

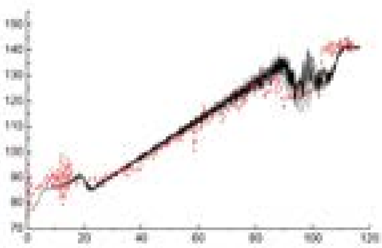
- A multi-rope friction hoist system is simulated using MFBD technology.
- Time reduction by MFBD technology which can simulate rigid bodies and flexible bodies together.
- Simulation of various load conditions using an intuitive user interface.



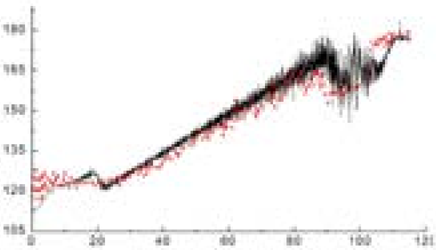
stress contour at 15s

## ◆ Outcomes

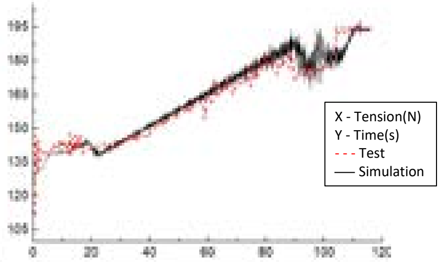
- RecurDyn accurately reproduced the behavior of the ropes allowing unwanted vibration and erratic behavior of the cables (flutter and cable excursions) that are often encountered in mining hoist machinery to be analyzed.
- Simulation results were in good agreement with experimental results
- The power requirements of the hoisting motors were predicted.
- RecurDyn simulation results provided useful data for fatigue evaluation of drum.



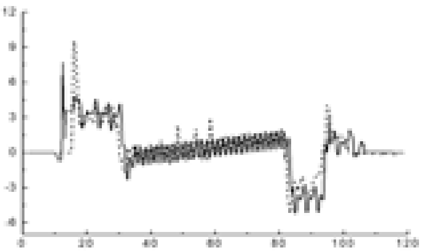
Tension in Hoist wirerope (No-load)



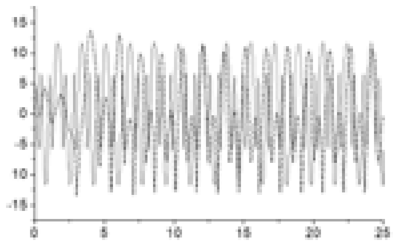
Tension in Hoist wirerope (15T)



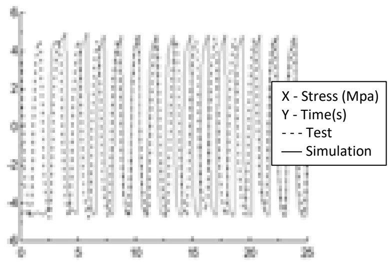

Tension in Hoist wirerope (34T)



Dynamic stress history (Position 1)



Dynamic stress history (Position 3)




Dynamic stress history (Position 7)

FunctionBay

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