

# **RECURDYN Solution Briefs**

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#### **Automotive**

### 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



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.

#### • 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

Change of oil behavior according to the guide configuration



#### **Automotive**

### 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



Toolkits

RecurDyn/Professional

Particleworks Interface





• 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



#### **Automotive**

### 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





#### Toolkits

RecurDyn/Professional

RecurDyn/FFlex



- 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

#### **Automotive**

### 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.



#### 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

- 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 gear



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





Order line obtained by simulation



Speed Reducer including planetary gear set

#### **Automotive**

### **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 buildup 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 enabled 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 rpm of interest
- ③ Analyzed the valve rotation at different speeds
- ④ Analyzed the valve rotation with different valve contact surface shapes

#### Key Technologies for Analysis

- Rigid multi-body dynamics used to quickly perform multiple simulations with different shape and rpm
- 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

#### Toolkits

RecurDyn/Professional



The carbon deposits around the engine inlet ports

RecurDyn correctly reproduced the valve behavior using various contact surface shapes





- Trial & error using physical prototypes requires more than half a year to achieve design improvement.
- Measuring and monitoring the valve rotation using experiment is 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.

#### 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 effect of contact surface shape and visual verification of valve rotation through trajectory display

#### Outcomes

- RecurDyn correctly recreated valve rotation for various camshaft rpm
- 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
- Analysis of transmission 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 gear



Watch the animation of engine valve



Model with rigid body valves and spring forces



3D contact surfaces

#### **Automotive**

# 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.
- <sup>(6)</sup> 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



## starDyna eXcearch

#### 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<sup>(1)</sup>
   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<sup>(2)</sup> 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.
- $\bullet$  It is now possible to estimate quantitative damage  $\beta$  from road profile kurtosis.

#### • Other Applications

- Driving simulation of passenger car on 3D road
  - Passenger comfort
  - Steering performance







Road profile (Height scale x10)

### 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



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

### salvagnini

A case from EnginSoft Newsletter #4, year 2019. ourtesy 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



A case from EnginSoft Newsletter #3, year 2019. ourtesy 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



RecurDyn/Professional

RecurDyn/FFlex

## eXcearch JBL

#### 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

#### 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/



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

#### **General Machinery**

### 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** 

Toolkits

RecurDyn/Professional

## eXcearch

#### 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





### 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



#### 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





- 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





- 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

### **Robotics**

### 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 and gear 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

- 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 gear



- 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



#### Toolkits

RecurDyn/Professional

RecurDyn/TrackHM

- 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 the robot

#### 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



Track assembly can be created easily using the track toolkit

#### 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 link.
- Also, graphical design of sprocket teeth profile and grouser of the track link is supported.

### **Robotics**

### **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

- 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 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.



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.

### **Electronics**

# 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

### SIEMENS

#### 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



#### Outcomes

- Identified the most critical design variables of the circuit mechanism.
- Devices with higher functionality require more complex assemblies, as shown here in the ACB switching 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.

### **Electronics**

### 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 a 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 profile.
- (5) Optimized the cam curve for smooth operation.
- <sup>(6)</sup> 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
 Recu

RecurDyn/FFlex

- 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 were 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



- ◀ 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
- Reproduce 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



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

Product: Solar array

Analysis Goal: 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

- 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 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

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- 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.

### **Home Appliance**

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

#### Product: Top Loading Washing Machine

Analysis Goal: 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





REGURDYN

#### 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

### Cost savings through compact track loader simulation

Product: Compact Track Loader Analysis Goal : 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









Toolkits

 RecurDyn/Professional RecurDyn/TrackLM

- Development of a compact track loader with good durability
- The flexibility 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

#### 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

#### 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



- 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 link.
- Also, graphical design of sprocket teeth profile and grouser of the track link is supported.



Track tension can be quantitatively reviewed



Accurate calculation of the track assembly



#### Contact

#### FunctionBay, Inc. HEADQUARTERS, R&D Center

5F, Pangyo Seven Venture Valley 1danji 2dong, 15, Pangyo-ro 228 Beon-gil, Bundang-gu,

Seongnam-si, Gyeonggi-do, 13487, KOREA

82-31-622-3700 www.functionbay.com

info@functionbay.co.kr







#### FunctionBay K.K. JAPAN

2F, Onoyakyobashi Bldg., 1-4-10, Kyobashi, Chuo-ku, Tokyo, 104-0031 Japan 81-3-3243-2031 www.functionbay.co.jp fbj\_info@functionbay.co.jp

#### **FunctionBay CHINA**

350 Xianxia Rd., Kechuang Bldg. Suite #106 Shanghai 200336, China86-21-5240-0270www.recurdyn.cninfo@pro-lambda.com

#### TAIWAN AUTO-DESIGN CO. CADMEN CO.

11F., No.68, Sec. 2, Xianmin Blvd., Banqiao Dist., New Taipei City 220, Taiwan (R.O.C.)886-2-2956-7575www.cadmen.com.twjohnson.liao@cadmen.com.tw

#### Function Dynamics (I) PVT. LTD. INDIA

301 Odeon Plaza II Sector 10, Dwaraka, New Delhi 110075 INDIA91-11-28083519bsridhar@functiondynamics.in

#### FunctionBay GmbH. GERMANY

Central Tower Landsbergerstr. 110 80339 Munich Germany 49-89-322-098-27 www.functionbay.de Info@recurdyn.de

#### EnginSoft USA LLC

7210 Virginia #100-6243, McKinney, TX 75071 - USA1-469-912-0504www.enginsoftusa.cominfo@enginsoftusa.com

#### FunctionBay Italy s.r.l. (Fabiano Maggio)

Via Giambellino, 7, 35129, Padova (PD), Italy +39 340 7640864 www.functionbay.it info@f

info@functionbay.it