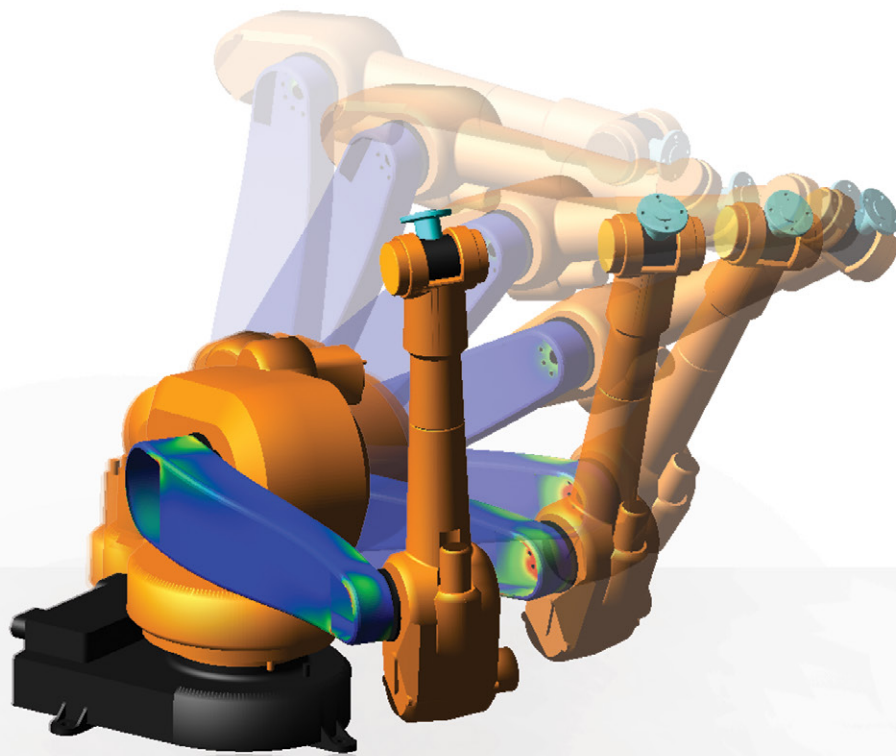


Designing Better Industrial Robots with Adams Multibody Simulation Software



Introduction

Industrial robots are increasingly being used in a wide range of applications where their speed, strength, accuracy and flexibility can provide advantages such as improving quality and reducing production cost. Designers of the new generation of industrial robots face many challenges such as increasing operating speed while maintaining positioning accuracy and avoiding excessive vibration in applications such as metalcutting where the robot is exposed to high levels of forces. Traditional methods of designing robots such as using equations or software to model kinematics and simple dynamics are losing effectiveness as robots become lighter and operate under higher loads, causing dynamic effects such as structural deformation and gear backlash to play an increasingly important role in robot performance.

Robot designers can increase the performance of their products by using Adams multibody simulation (MBS) software to simulate the transient dynamic behavior of the complete robot mechanism and control algorithm. Adams goes far beyond kinematic modeling to provide a complete working prototype of the robot and task that it is performing, including handling, manufacturing or anything that can be done in real life. This approach enables robot designers to understand the effects of component deformation, contacts, friction, gear backlash, vibration, etc. so they can calculate the robot trajectory with a much higher level of accuracy. Adams makes it possible to accurately simulate and diagnose the dynamic performance of the robot under any operating scenario prior to building a prototype, making it possible to increase robot performance by evaluating many different design configurations and control algorithms while getting the robot to market earlier by reducing the amount of physical testing that needs to be performed.



Pushing the Performance Envelope Challenges Robot Designers

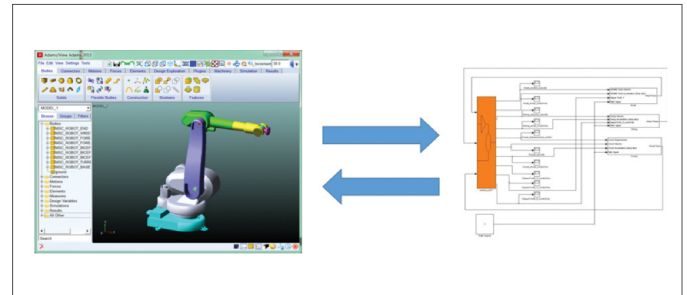
In a highly competitive market, robot designers must deliver a product that provides the highest possible level of speed, accuracy, durability, and other performance parameters at the lowest possible cost. When a 5% speed advantage is often the difference between making and losing a sale, robot designers need to push the limits of the design process. For example, robot designers can use higher torque motors or they can use lighter arms to reduce the time required for the robot to reach its final position.

As robot designers push the performance envelope, arms and other components bend to a degree such that this deflection becomes important in calculating the joint motion that must be undertaken to achieve a given robot position. Higher torque and lighter arms also make the robot more prone to vibration so it becomes more critical than ever before to determine the natural frequency of the robot and ensure that it is far from any operating frequency of the robot. More powerful robots also increase the demands on the gear train of the robot, increasing the importance of effects such as gear rattle and backlash and also making the bearing design more critical.

But most robot designers are still using the same design tools they have used for decades. Trajectory planners that incorporate kinematic models or simple dynamic models are typically used to establish the path followed by the end effector to reach the desired spatial position while tracing a smooth and continuous motion during the motor acceleration and deceleration stages. But even when encoders with very high levels of accuracy are used, the ability of robots to move to an absolute XYZ position and ABC orientation is limited by effects such as deflection, gear backlash, thermal expansion and manufacturing variation. The link flexibility problem can be solved analytically with equations but this approach requires a high level of mathematical skills and a considerable amount of time. The complexity of the analytical method increases exponentially as the degrees of freedom and geometrical complexity of the robot increase.

Another challenge for today's robot designers is understanding the value of the forces applied to the various joints of the robot. As lightweighting is increasingly used to improve robot components, these forces need to be accurately estimated at an early stage in the design process in order to size robot components to deliver a competitive product. Joint forces depend to a large degree on the stiffness of the bearings and beams of the robots so traditional design tools are not able to provide accurate predictions. There is also a growing trend towards the development of collaborative robots that can be operated safely in the presence of human operators. A critical factor in the design of these robots is determining the amount of forces that would be applied by the robot to an operator in the event of a collision in order to avoid operator injury.

The design of the robot's control algorithm also has become much more critical and difficult in today's more competitive environment. In order to deliver high speeds while maintaining or increasing positional accuracy, the control algorithm often needs to take dynamic effects, such as the flexibility of the robot and bearings and the stiffness of the geartrain, into account. Meeting the delivery schedule often requires that the control algorithm be designed simultaneously with the robot itself, yet current design methods provide little information on the dynamics effects needed to make sound design decisions.



Adams model can be co-simulated with control system model

One more example of dynamic effects that need to be considered in robot design is the management and guiding of cables. A group of systems integrators recently cited cable management as the number one reason for downtime in robot cells. Traditional design methods provide no way to know the deformed shape of the cables until the prototype testing stage.

Adams MBD Software Predicts Robot Dynamic Performance prior to Prototype Stage

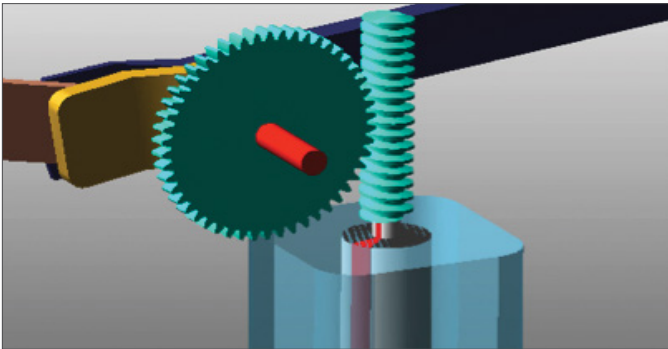
Adams MBD software goes far beyond traditional robot design tools by providing large displacement dynamics modeling capabilities that capture the full gamut of real-world complexity. Adams overcomes the limitations of kinematics solutions by simplifying the task of modeling the dynamic performance of rigid and flexible bodies, gears, bearings, motors, joints and other robot components, not to mention objects with which the robot interacts. The result is that Adams enables robot designers to evaluate the dynamic performance of their products as an entire system in the early stages of the design process prior to the availability of prototypes.

Adams offers a wide range of flexible body modeling options to provide an accurate understanding of the dynamic behavior of any robot component. Adams Flex allows importing finite element models from most major FEA software packages and is fully integrated with Adams package. The ViewFlex module in Adams View enables users to transform a rigid part to an MNF-based flexible body within the Adams environment. FE Part is an Adams-native modeling object that provides a fast way to model geometrically nonlinear parts in system model. Adams-Marc Co-simulation enables users to perform real co-simulation between world-class Marc nonlinear FE technology and Adams. Based on implicit nonlinear finite element analysis, Adams MaxFlex allows for the representation of geometric nonlinearity (large deformations), material nonlinearity, and boundary condition nonlinearity in Adams models.

Robot designers can use Adams Machinery to create rigid body gears that accurately simulate gear backlash and rattle effects or use the Adams Gear Advanced Technology (AT) plugin to create even more accurate flexible gear models. They can use the Adams Bearing Advanced Technology (AT) toolkit to create flexible bearing models simply by defining a few geometric parameters and material properties.

Adams Offers 3 Ways to Simulate Electric Motors

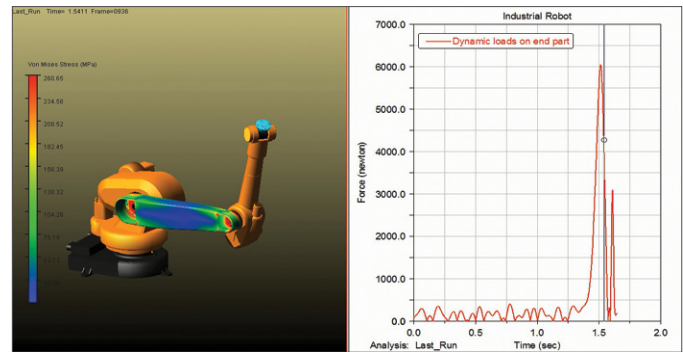
Adams provides three different methods for modeling electric motors. In the curve based method, the motor torque is defined via a user-defined torque speed curve. With the analytical method, the motor torque is defined by an equation set whose parameters are specified by the user. Users can also choose the external method in which either an Easy5 or a MATLAB Simulink model defines the motor torque. The electric motor module can be used to perform fine position control with precise torque representation. Users can evaluate the effects of vibration on the system introduced by the oscillatory nature of the motor torque signature. They can also study the dynamic effects of the rotating masses within the motor in systems with very large motors, such as the load prediction at mount points or noise/vibration/harshness (NVH) concerns. Finally, the module provides a more sophisticated motor sizing method than simply applying a motion in the model and looking at the torque it requires.



The Adams mechanical model can then be integrated with a control system model developed using a software package such as Easy5® or MATLAB®. Engineers can graphically model mechanical systems to a much higher level of fidelity than is possible using the conventional approach of writing equations of motion or using simple 1D mechanical models. Alternatively, actual controllers from the controls design software can be imported into the MBD simulation environment.

How Adams Enables the Design of Higher Performing Robots

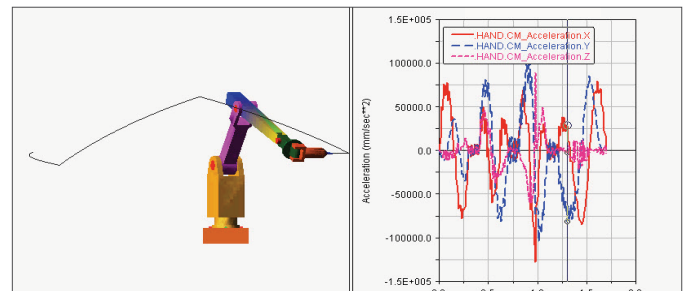
The ability of Adams to capture component deformation by incorporating flexible bodies such as robot arms and gears into simulations makes it possible to calculate robot arm trajectory with a much higher level of accuracy than traditional methods. Incorporating component deformation into dynamic models also enables robot designers to accurately predict the loads experienced by all robot components. Robot designers can use Adams simulation to maximize the speed of the robot by increasing motor torque and reducing the weight of components without exceeding specified loading values or generating excessive vibration. When excessive loads are seen on specific components, robot designers can change the robot design or control algorithm and determine the impact on the component loading. Robot designers can also easily determine the loads that would be exerted on human operators in the event of a collision to simplify the process of designing collaborative robots.



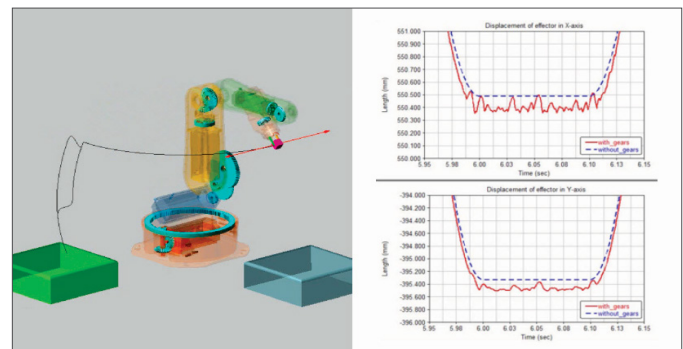
Calculating robot arm trajectory with component flexibility taken into account

Adams enables robot designers to determine the natural frequencies of robot designs and predict what level of vibration will be experienced in specific applications. Robot designers can verify that the operating frequency stays away from the system natural frequency to avoid resonance effects. They can perform system level vibration analysis in order to optimize the performance of the robot while ensuring that vibration remains below acceptable levels. Robot designers can also use Adams models to study the effects of gear backlash on robot trajectory, predict the contact force between gear teeth, study the effects of gear friction and evaluate and mitigate gear rattle.

Robot designers can also fine-tune the control algorithm early in the design process to increase the positional accuracy of the robot by taking the dynamic response of the robot arms and gear train into account. The ability to develop and fine-tune the control algorithm using a software prototype rather than a physical prototype of the robot makes it possible to evaluate a much wider range of control strategies than would be practical using current design methods in



MBD predicts system level vibration of a robot



Determining the effect of gear backlash on moving trajectory

which the control algorithm cannot be validated until the physical prototype is available. For example, control algorithm designers can evaluate different strategies for compensating for loads based on structural deformation, performance of different tasks, and the effects of manufacturing variation and wear on system behavior.

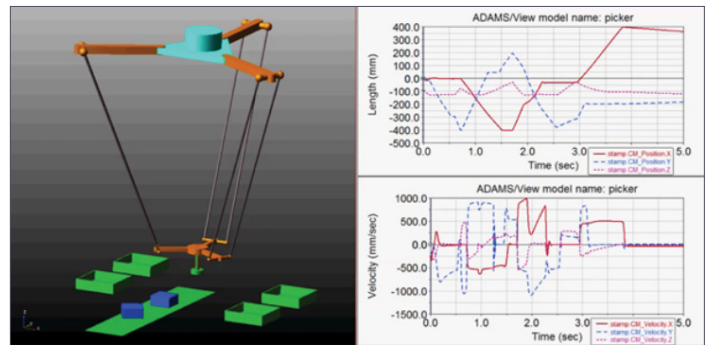
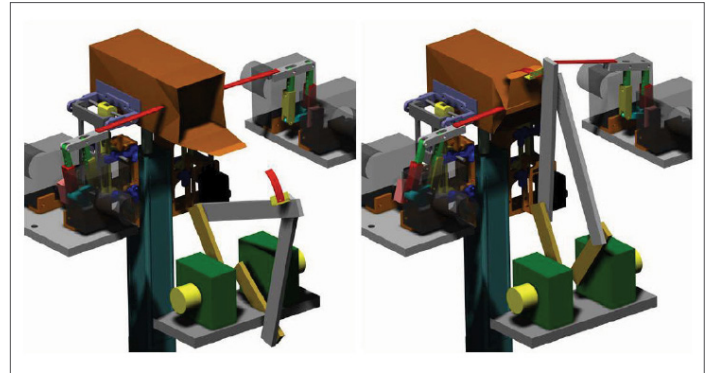
Adams also enables robot designers to evaluate the performance of different approaches to cable guidance and management by simulating the deformed shape of the cables and their motion profile in response to robot arm movement early in the design process. FE Part, an Adams native modeling object which is accurate for geometrically nonlinear parts with large deformations, greatly reduces the modeling time and effort required to accurately model large deformation cases with the Adams environment. Simulation makes it possible to try many different cable positions, orientations and clipping options early in the design process prior to the availability of a prototype.

Adams can also be used to develop robots that can manage complicated packaging operations and adapt to new packaging styles as they are developed. One of the greatest challenges involved in the design of the carton and packaging equipment is understanding the behavior of the carton during the folding process. An Adams model of both the carton and robot can be used to simulate the folding operation. Each moving element of the machine is connected kinematically to the carton model in order to fold the carton. This is accomplished by using Adams to develop the inverse kinematic solution of the fingers. The resulting joint angles are input to the multibody rotational and linear actuators to drive the simulation.

Adams is conducive to design studies and designed experiments that improve product performance by understanding interaction of key parameters and performance goals. The MBD software automatically modifies the model, performs each simulation and provides the user with results for viewing. Design of experiments (DOE) goes one step further by varying the values of all factors in parallel. This approach determines not just the main effects of each factor but also the interactions between the factors so it becomes possible to identify the optimal values for all factors in combination.

Conclusion

To summarize, dynamic performance has become crucial to industrial robot performance yet today's design methods provide little information on dynamic performance until late in the design process when a prototype is built and tested. At this stage it is very expensive



Using a design study to optimize robot performance

and time-consuming to evaluate design alternatives so designers usually face strict limits on the number of design alternatives that can be evaluated which in turn limits the performance of the finished robot design.

Adams enables robot designers to evaluate the transient dynamic behavior of a proposed robot design in much less time, at a lower cost and at an earlier stage in the design process than would be required to obtain the same information from prototype testing. Using Adams, robot designers can increase operating speed while maintaining precision positioning and avoiding vibration, validate and optimize the control algorithm and evaluate the ability of a proposed design to perform a wide range of applications. With Adams in their toolbox, robot designers can create a better product in a shorter period to ensure success in an increasingly competitive market.

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