Multi-body Simulation as the Integration Platform for a Virtual Manufacturing Machine[1]

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Abstract

The development of component placers for electronics production is a demanding job as the requirements for speed and accuracy are challenging. This article presents an approach to build a virtual prototype on the basis of a multi body simulation model. It includes moving parts, flexibility, vibrational behaviour as well as thermal distortion. Special attention is given to modelling a linear joint on a flexible body. Finally, the application of the module Timing Mechanism for simulating the axis-driving toothed belts is discussed.

1 Introduction

The requirements for developing manufacturing machines are increasingly demanding. Especially production equipment for electronics production always has to meet the demands for higher accuracy and speed. The pace for machine development is set by the trends for miniaturisation and higher lead counts of the electronic components. This makes it necessary to have software and simulation tools for virtual prototyping on hand which can be used to predict the machine's operational behaviour.

2 Presentation of the Problem

The machine being studied is an SMD component placer used in electronics manufacturing. Its purpose is placing electronic components onto printed circuit boards. This step is the most time consuming one in the process chain for electronics assembly as every component has to be treated individually. Therefore, the specifications for this type of equipment are demanding in regard of both, working speed and working accuracy.

To give an idea of these specifications, take a standard general purpose component placer which has to guarantee a positioning accuracy of 50µm and better. The working speed in this case is some 1800 components per hour which represents two seconds per placement of one component. High-speed systems for small components of about 0.5 x

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[1] The results presented in this paper have been elaborated in the project „Ermittlung der Maschinenfähigkeit durch integrierte Simulation des thermischen und dynamischen Verhaltens" (Determining the machine capability by integrated simulation of thermal and dynamic behaviour) which is part of the Bavarian Research Cooperation Simulation Technology FORSIM funded by the Bayerische Forschungsstiftung.

0.25 mm^2 size have a throughput of 50000 components per hour and more. For future developments, the requirements will be even more challenging. Therefore, the application of effective simulation tools is crucial.

The machine for which the virtual prototyping approach is presented is a Siplace F4 general purpose placer which can place both, miniaturised as well as high lead count components. Therefore, this machine has to be able to place accurately and fast. In order to meet these requirements the machine's kinematics is basically cartesian. The axes are driven by electrical motors and toothed belts. The Y-axis is moving a gantry on which the entire X-axis drive and the placement head are attached. The Z-stroke for picking and placing the electrical components as well as the C-rotation for modifying its orientation are provided by the placement head. A CAD representation of the entire machine with its axis names can be seen in Fig. 1.

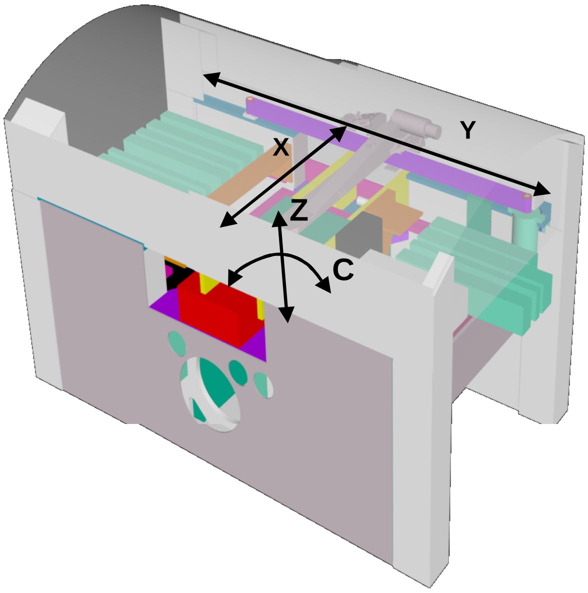

Fig. 1: Basic kinematics of the placement system Siplace F4

The working cycle for the placement machine (cf. Fig. 2) starts with the picking of a component. Therefore the placement has to be exactly above the component which is picked with a Z-Movement only. As the orientation of the component in the feeder may vary for some one to two degrees which is not acceptable for fine pitch components its orientation has to be determined with an camera and then the component is rotated into its placement orientation with the C-axis. This movement and the following one towards the placement position are in the XY-plane. A superposed Z-movement would result in a collision of the placement head's nozzle and a non-moving part of the machine. After reaching the designated position above the printed circuit board (PCB) which is being machined the component is placed with a designated Z-stroke. After the nozzle has re-turned to the 'up'-position, the next component can be picked.

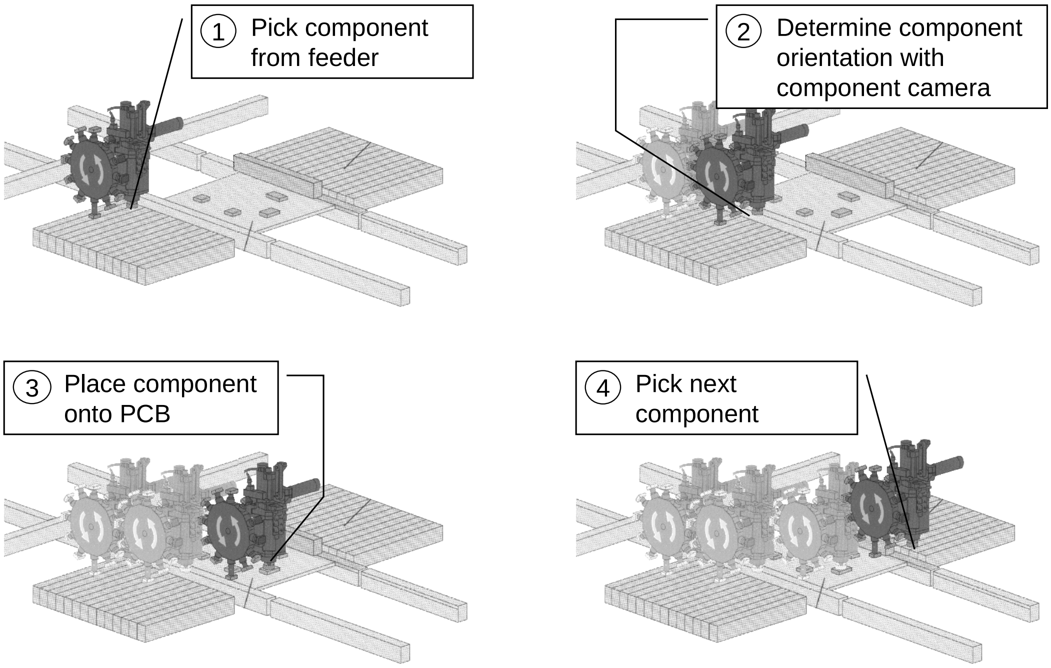

Fig. 2: Pick and place cycle (simplified)

In this working cycle which may only take one second high accelerations of the gantry occur while the placement head is travelling along it. As experiments on the machine have shown [5] there are maximum accelerations of 2g in the Y-axis and of 3g on the X-axis resulting in nearly 4g for the component. Hence the flexibility of the gantry cannot be neglected. Furthermore, measurements have shown a considerable influence of thermal distortion caused by the drives and electronics on the working accuracy [4].

In order to optimise the entire manufacturing system it is necessary to provide a model which reflects all these effects, in other words, to build a virtual prototype. This virtual prototype has to integrate different views on the machine and the corresponding partial models for the mechanical, thermal, technological and control influences. In order to represent the reality as good as possible within the simulation model the effects modelled within these partial models are to be integrated. The multi-body simulation (MBS) is the software tool which allows this to the furthest extent. Other possibilities would be to integrate the models into a finite element model (FEA) or a block simulator such as a computer aided control engineering package (CACE). As the finite element approach is normally restricted to small deflections, the influence of different control concepts cannot be examined. A block simulator on the other hand, requires a very high level of abstraction so that there is no direct link to the CAD model.

For this reason, a multi-body approach was chosen, utilising Adams's links to finite element and control design tools. By applying different ambient conditions to the virtual prototype and thus simulating the machine's behaviour towards various operating conditions, environmental influences etc. the potential machine capability and its robustness can be studied.

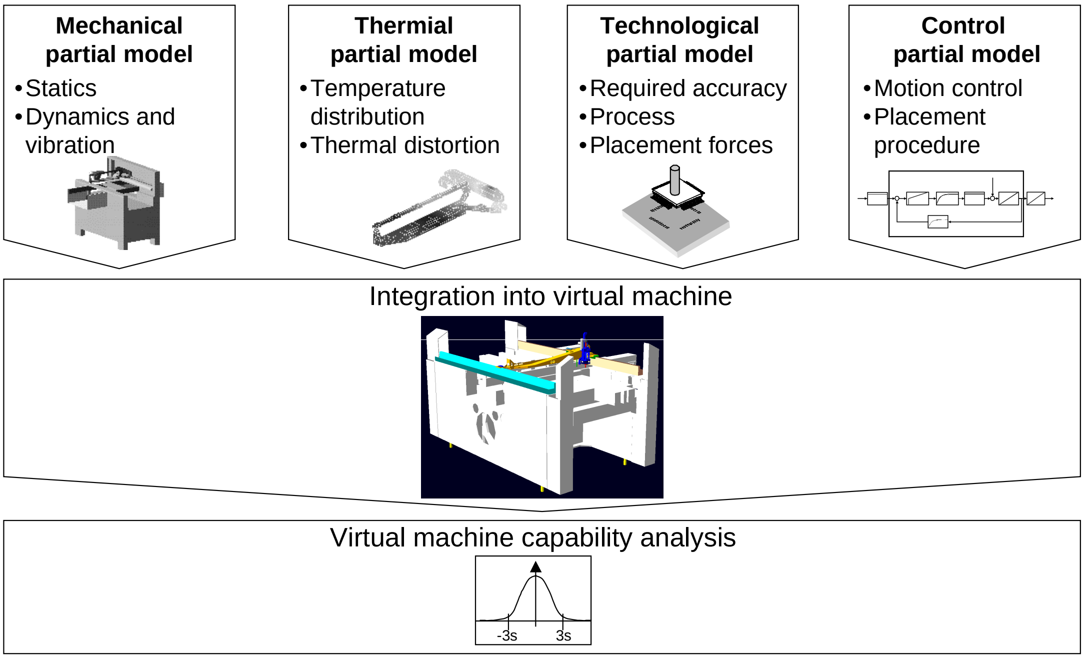

Fig. 3: Integrating the partial models into a virtual placement machine

3 Multibody Model of the Placement Machine

A rigid body model based on the CAD data was created as the basis for the virtual placement machine. In this first model ideal(ised) joints had been used some of which have been later replaced by more realistic constraints. As this paper focuses on the possibilities, perspectives - and limits - of using flexible parts and connections and will not discuss standard elements such as rigid bodies, springs and ideal joints in detail.

The system's kinematics is basically cartesian, and so linear joints have been foreseen for most of the relevant connections. Considering that the point of force application continuously changes during the movement when a load is travelling along a flexible body, a connection topology had to be developed. This topology has to take into consideration the correct deflection line and joint forces.

Using flexible bodies, Adams/Flex allows to introduce modal loads which are independent from the dynamics situation of the model. This approach was used to apply thermal loads to the flexible body and thus combine thermal and dynamic loads.

As toothed belts are the machine elements to transform the rotational movement of the electrical motor into the translation of the head and gantry, Adams/Engine's new feature Timing Mechanism was evaluated.

3.1 Special features for Modelling the Flexibility of Machine components

The placement head is moving on a linear guidance. Thus, the contact point between the guidance and the corresponding carriage varies with the position of the head along the X-axis. To correctly model these dynamics is a crucial task for which there is no standard modelling element available in Adams. Anyway, some special-purpose customer-specific solutions exist, e.g. [1] which are not available in the software distribution. Hence a model has been developed in the following manner: (figure 4) The guidance beam is discretised and attached to the gantry by fixed joints representing the bolts. The beam elements themselves are connected to each other via bushings. The joint between the sliding carriage and the guidance is modelled using self-defined general force elements. Their formulation is based on an impact function for the Z and Y degrees of freedom and a spring - damper function for the rotational degrees of freedom. The following figure presents the principle connection topology.

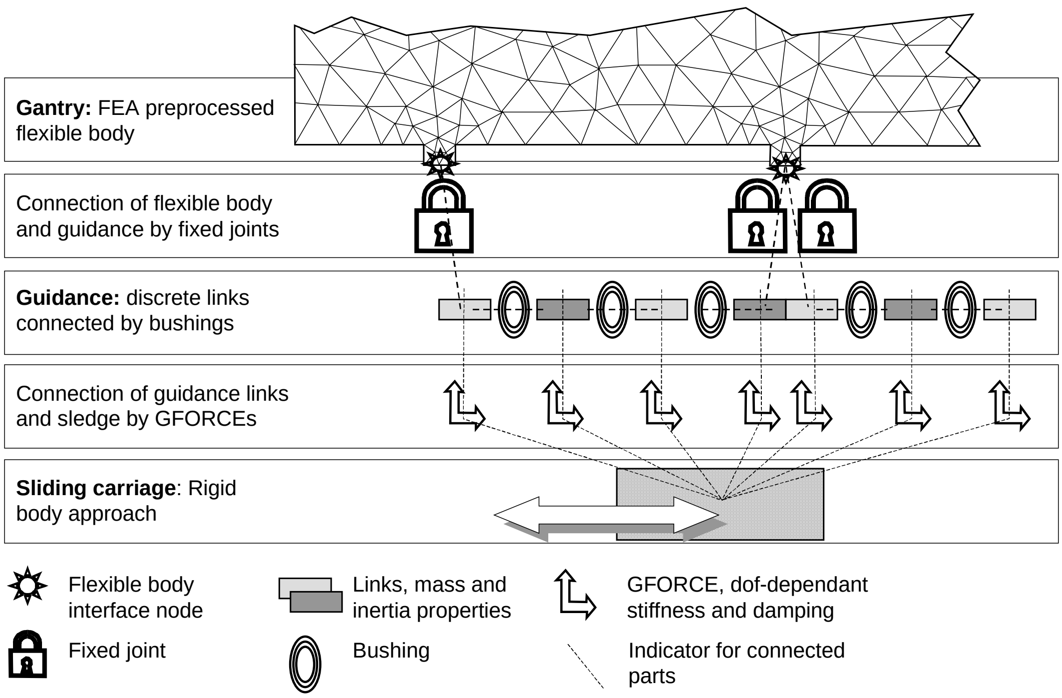

Fig. 4: Connection topology for a linear joint on a flexible body

Using this topology the user has to provide a template for the general force. The input information of this function is the impact parameters describing the stiffness in the Y- and Z-directions and the spring and damping rates in for the rotational stiffness. If friction in the X-direction is a concern, a force component can be introduced as well. This force would be a function of the placement head's velocity in the X-direction. The main advantage of this approach is the fact it only uses standard modelling features. The time for building this piecewise flexible linear joint for ten interface nodes is about three hours for an experienced user. In Figure 5 the results for the joints' Z-forces are compared to those of an analytical calculation for a cantilever beam fixed on both ends. As expected, the function is piecewise steady and gives a good approximation of the analytical function. If a higher accuracy is desired, the number of links can be increased.

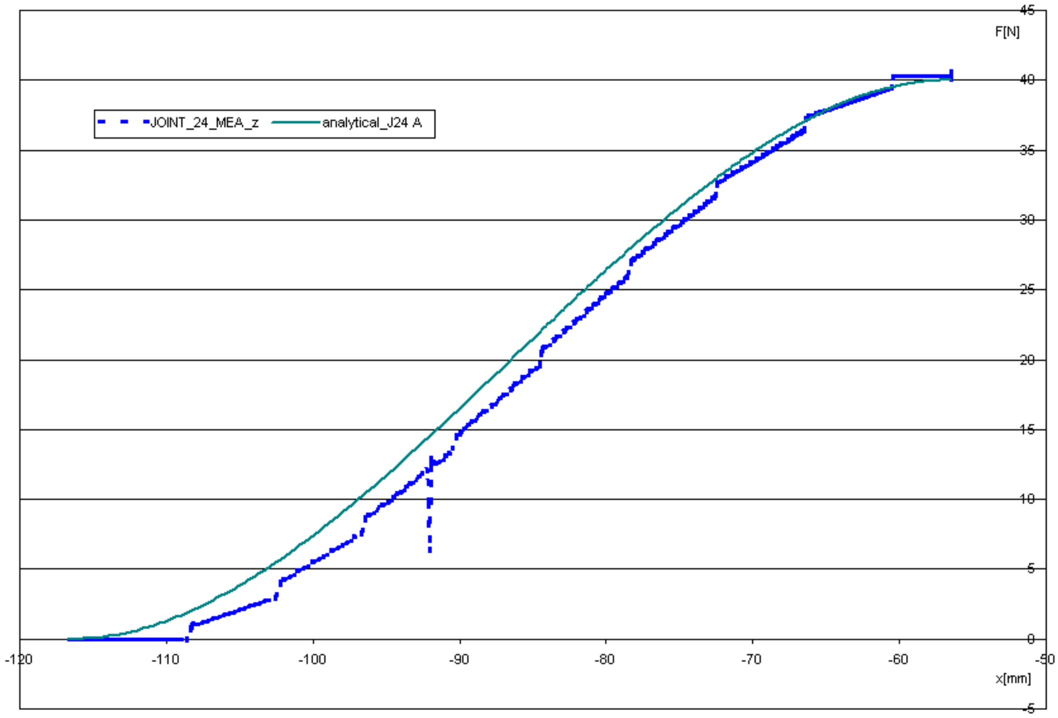

Fig. 5: Comparison of analytical and simulated joint force for a “flexible linear joint" (double sided fixed cantilever beam)

3.2 Introduction of Thermal Loads into the Multibody Approach

The dissipated heat from motors and other electronic components has a considerable effect on the working accuracy of the component placer. The multi body approach which has been chosen is, however, normally not capable of dealing with thermally induced stress and distortion. By using Adams/Flex’s modal load option, it is nevertheless possible to circumvent this problem. The procedure is as follows:

The thermally caused distortion is calculated from the constraints and the temperature field within the FEA code. The FEA solver computes the stresses, nodal displacements and a field of nodal forces which causes the same stresses and displacements as the thermal load. This load case is then included into the modal neutral file (MNF) discribing the flexible body. As the standard procedure for this requires about twelve single steps of each of which has to be done manually with high accuracy, this process was automated using a software tool: It reads in the finite element mesh (DAT-file) and FEA-solver specific commands (mnfx.alt) which are the standard input files and the NEU-file which contains the force field information and a specific header which normally has to be edited manually. Its output is the MNF-file containing the modes, mode shapes and load cases. The flexible body can now be used in Adams, for simulating different load cases and dynamic loads (Figure 6). It has to be checked that the constraints in the multi-body simulation and in the FEA analysis are equivalent.

For this project, the pre-processor Nastran for Windows (Femap) was used together with the MSC Nastran solver.

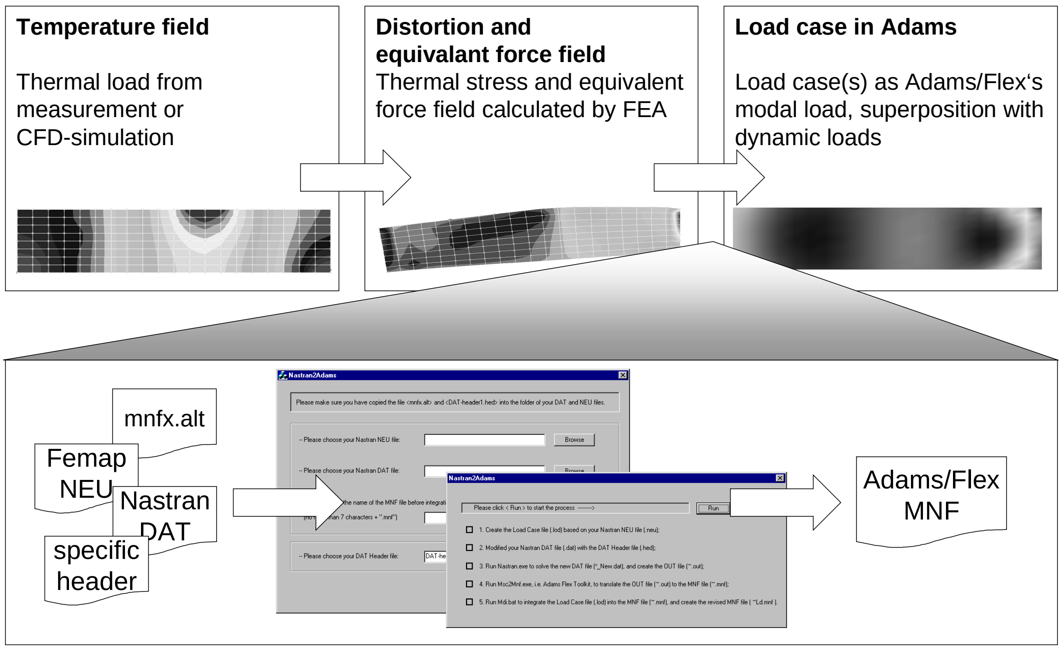

Fig. 6: Introducing thermal loads in Adams

3.3 Modelling the axis-driving toothed belts

The drives of a manufacturing machine have a significant influence on the working speed and accuracy of this manufacturing system. The motor normally is the only point where the machine control can influence the behaviour while the machine is operating. Therefore it is very helpful to know the transfer function between the motor shaft and the tool center point. The parts of the model mentioned above can describe the response to a driving force attached to the tension jack. Nevertheless is this only a part of the required transfer function. In the placement machine, the force is generated from the motor torque via a toothed belt. As it is possible to include the drive’s electrical side via the link to a CACE programme describing this system in a block-oriented way (or by a sophisticated Gforce), still the toothed belt's behaviour is missing. Experiments have shown that this drive concept can have a significant influence on the accuracy. This is due to the vibrations induced by the ongoing change of tooth and gap contact in the pulley and decreasing tension.

Therefore Adams's module Timing Mechanism was used which is part of the Engine simulation package for combustion engines (cf. figure 7).

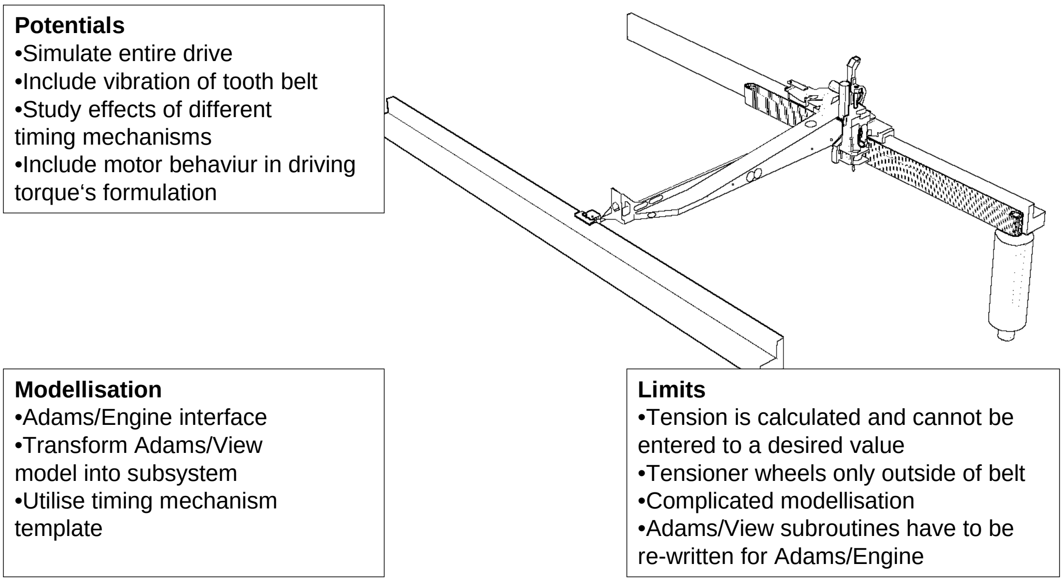

Fig. 7: Timing mechanism model for the Y-axis

The modelling philosophy of Adams/Engine requires that the main part of the machine is encapsulated into an Adams/Engine subsystem. This can then be combined with the toothed belt template. Special attention has to be given to the fact that some links of this belt are attached to the moving gantry in the tension jack. This can be realised when a fixed joint between the tension jack and the relevant belt segments is already modelled in the template definition phase. The toothed belt is modelled by Adams Timing Mechanism as a sequence of tooth and gap elements which are connected by joints and bushings. During the simulation phase, the elasticity of each of these connections and the contact of link and pulley has to be calculated resulting in considerable calculation costs.

As the Timing Belt module was designed for a different purpose, there are some limitations for its use for general machinery applications: The modellisation is quite costly as the Adams/View model has to be formalised according to the conventions of the template-based Adams applications. That includes the fact that all user-written subroutines have to be re-written.

The most severe problem is the following one: In the placement machine, the second wheel is not a toothed pulley but a blank tensioner. Its distance from the motor is used to set the tension in the system. Adams Engine's concept comes from a different point of view: As the distance between crankshaft and camshaft in a combustion engine has a value which is determined by the function of the motor. Then the tnesion in the belt is calculated from its length.

As the toothed belt module is a very interesting option, not only for placement machines, but as well for every high-accuracy application in assembly and machining, it would be desirable to have it on hand also outside the Engine package.

4 Summary and Outlook

Virtual prototyping using a multi body approach can include nearly all aspects of a manufacturing machine as shown in figure 8. This includes rigid body movements, vibrations using flexible bodies, drives and friction. A special problem in simulating systems with cartesian kinematics is the sliding of masses along flexible point. As the point where the force is applied is continuously changing a discretisation of these guidances has been introduced.

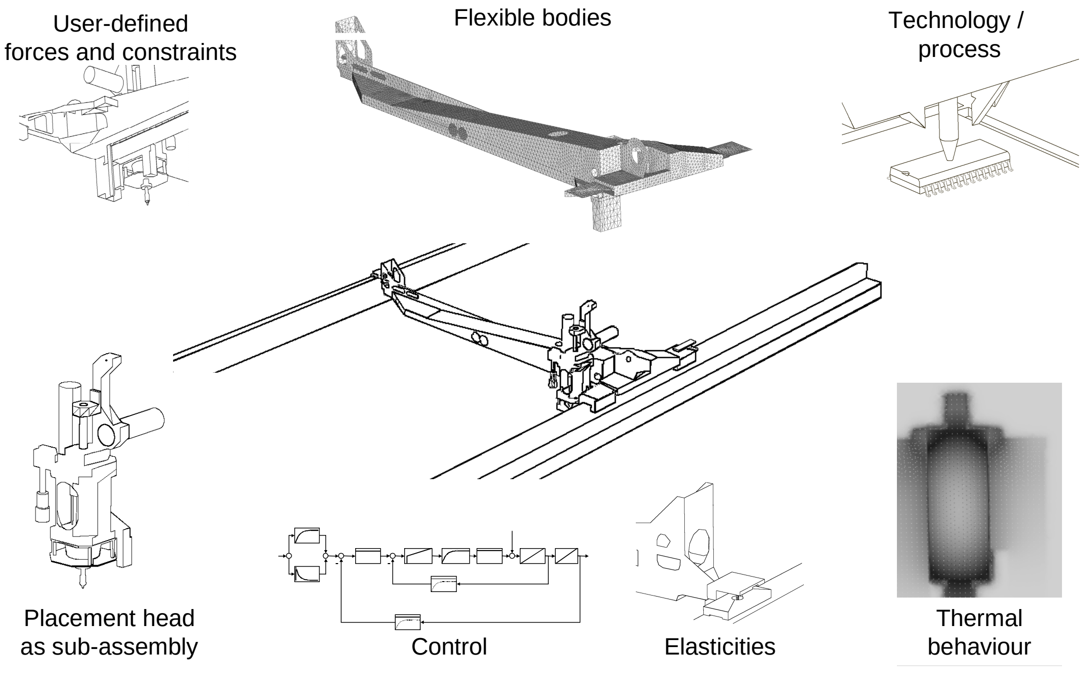

Fig. 8: Content of the virtual prototype for a component placer [3]

Using flexible bodies, even thermal loads and load histories can be simulated in their superposition with the dynamic system behaviour. Finally, the drives' behaviour is an important area of modelling. Here, CACE tools and user-defined forces can model the motors. The behaviour of the toothed belt transforming rotational to translational movement can be modelled using a special module within Adams. The appraoch gas been elaborated for a component placer used for electronics production. The results, however, can be easily transferred to applications with similar requirements regarding accuracy and speed. In the future, the model will be extended with a process model of the placement of the component into the solder paste and detailed friction on the driven joints. In order to utilise the information of the virtual prototype for planning a manufacturing line, a linkage from multi body simulation to discrete event simulation is under development as well. This makes it possible to take the behaviour of a brand-new machine into account for production line-planning [3].

5 References

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