Concept Evaluation for a Voluntary Milking Robot System

Jan Johansson
Department of Machine Design
Royal Institute of Technology, KTH
SE-100 44 Stockholm, Sweden
E-mail: janj@md.kth.se
Phone: +46 8 790 85 05
Fax: +46 8 20 22 87

Keywords: Modeling, Behavior Simulation, MBS, Design Process Model

Abstract

The intention of this paper is to report the use of ADAMS in an agricultural scope and to present an approach to modeling and behavior simulation integrated in the product development process.

In order to increase the efficiency in dairy milking, a milking system, the Voluntary Milking System (VMS™), is under development by DeLaval AB. The productivity increases due to voluntary and multiple milkings per day. Furthermore, the time consuming and strenuous milking task is automated. The VMS™ is a part of a complete barn layout where the cows can move freely.

In order to determine system properties such as eigenfrequencies beforehand, a modeling approach is preferable. A strategy incorporating modeling and simulation in product development activity [Andersson 97] is used. One important part goal of the modeling was to create an agile and fully parameterized model. A high degree of changeability is desired for concept evaluation purposes. The system has been divided into three subsystems: the stall, the robot and the control system.

This paper will describe one part of this concept i.e. the robot subsystem and the modeling and behavior simulation of it. The determination of eigenfrequencies and their respective modes for the different part models and for the whole robot system is presented in this paper. Furthermore, an analysis of the work area estimation is presented.

This work has been done in co-operation between DeLaval AB and the Department of Machine Design at the Royal Institute of Technology (KTH).

1. Introduction

The main aim of this paper is to present the use of ADAMS as a tool in a systematic modeling and behavior prediction process. This has been carried out in an agricultural scope as a co-operation between DeLaval AB and the Department of Machine Design at the Royal Institute of Technology. The research carried out is focused on strategies for using commercial Computer Aided Engineering (CAE) - tools for modeling and behavior simulation for evaluation of performance properties of product concepts.

The Voluntary Milking System, VMS™, under development by DeLaval AB (former Alfa Laval Agri AB) is an integrated part of an entire barn layout including a loose house and feeding stations (figure 1). The intention with the system is to relieve the farmer of the milking task and to increase milk production.

The cows' health is also an issue to be considered and with the voluntary element and the fact that the cows can move freely throughout the barn it must be considered as an improvement. The milk production increases with the implementation of voluntary milking in terms of more milkings per day compared to the traditional two-times per day milking scheme [Wittenberg 93], [Honderd et.al. 91]. A European test [Hogeveen et. al. 96] of a similar system has shown that 97% of the cows go voluntarily to the system when introduced to it. This indicates that there are no or minor problems with the transition from the traditional milking stalls to an automated stall.

Figure 1, The VMS™ from DeLaval AB, [DeLaval].

2. Systematic Modeling and Behavior Simulation

Used here is a modeling and behavior simulation strategy (figure 2) suggested by Andersson [Andersson 97]. The proposed strategy supports the systematic use of simulations in order to predict product behavior. Simulation can also be seen as a driver of the design process as suggested by Sellgren [Sellgren 99].

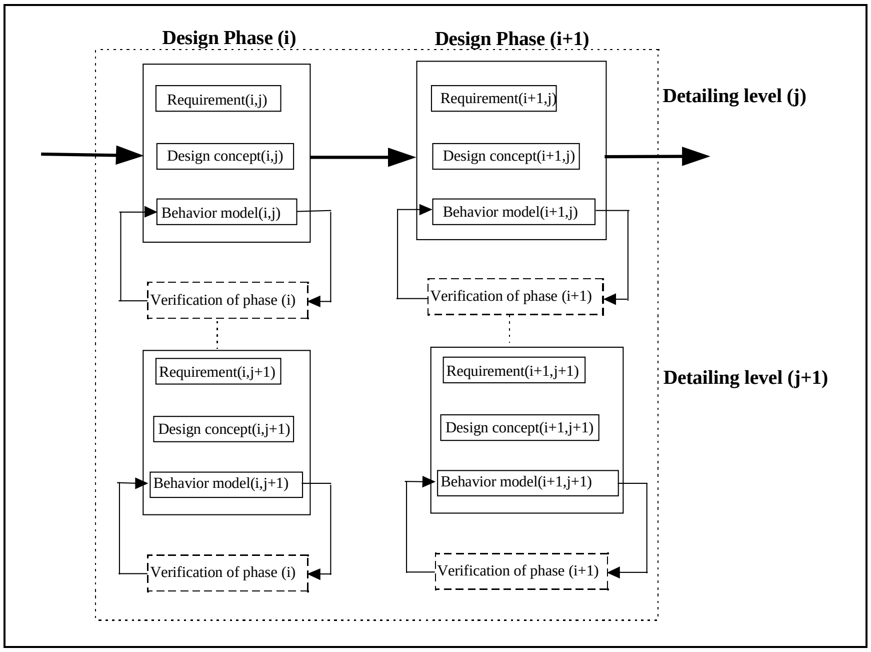

Figure 2, General design process model presented by Andersson [Andersson 97].

The general design process model (figure 2) presented by Andersson [Andersson 97] focuses on the use of modeling and behavior simulation in product development. This model is used in the MOSAIC project [Andersson 98] and has been used in this work.

Furthermore, this work is also influenced by the description of a product process model made by Pahl and Beitz [Pahl & Beitz 96]. A systems view [Pahl & Beitz 96] has been utilized when identifying the subsystems the VMS™ consist of, figure 3. This is a way to simplify the modeling and behavior simulation process as the subsystems can be handled separately. Complex systems can hereby be divided into manageable structures, e.g. subsystems. The decomposition level is governed by the system complexity. When the submodels have reached such a state of completion that, they are considered adequate for the intended purpose, they are connected into the complete system model. The purpose here is to be able to build system models, which are configurable for different problem statements.

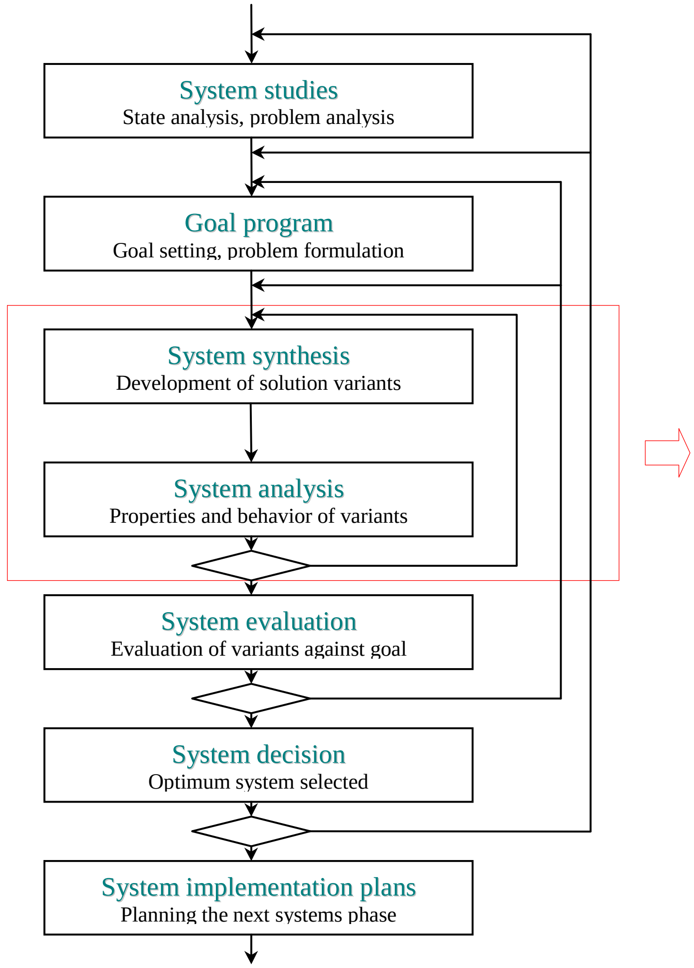

Figure 3, Steps of systematic approach [Pahl & Beitz 96].

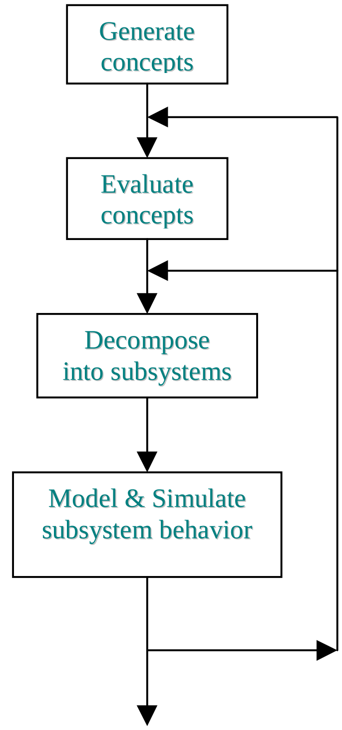

Figure 4, Decomposing of systems into subsystems with a prediction product behavior view adapted from Ullman [Ullman 97].

An alternative approach, based on a design process model presented by Ullman [Ullman 97], is also given in figure 4. The focus in this model is upon development and evaluation of product concepts. This is an area where the use of simulation tools is particularly beneficial. This model can be seen as an alternative model to the synthesis – analysis part of figure 3 (outlined). Although, modern CAE software is very powerful the use of it in industry is still limited. The approach in this paper has been to combine systematic modeling and simulation with commercial CAE – tools to show the potential benefits to industry.

3. Modeling the Voluntary Milking System

The VMS™ was divided into three subsystems: the robot, the stall and the control system (figure 5). The modeling and behavior simulation activity started with the robot subsystem. This far in the modeling process the stall has been modeled as the ground part.

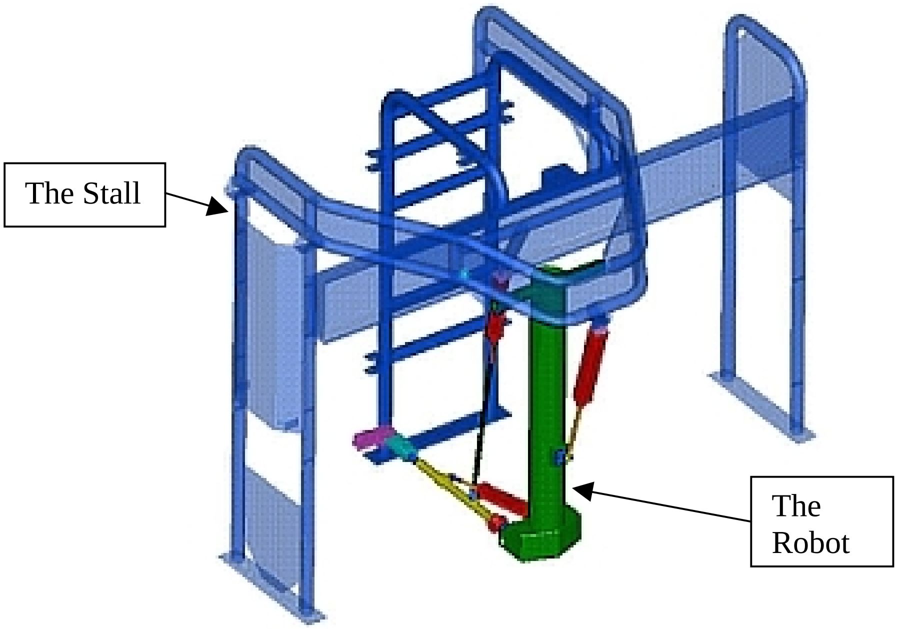

Figure 5, The VMS™ modeled in I-DEAS™.

3.1 Modeling Approach

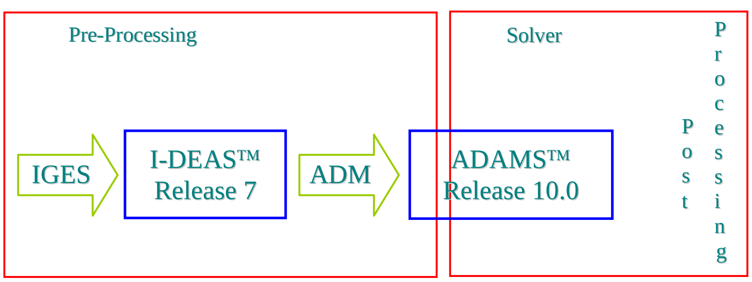

Figure 6, Modeling approach, Software utilized.

I-DEAS™ release 7 from Structural Dynamics Inc. has been used as part of the pre-processing activity. Geometry models for the parts were imported via the neutral file format IGES and transformed to solids. The part models were then assigned material and thus given mass and mass moment of inertia. An assembly of the parts was imported to the 'Mechanism Design' module where the creation of joints and the introduction of a load case took place. Using the ADAMS specific export command the model were transferred out of I-DEAS. The resulting ADAMS/Solver Dataset – file was subsequently imported to ADAMS/View.

The geometry from I-DEAS has not been utilized further. Instead, simplified geometry, i.e. cylinders, was created in ADAMS. When varying parameter values that influence lengths of part models its preferable to relocate the center of mass and mass moment of inertia. This makes the connection between geometry and part model properties no longer of interest. Consequently, the geometry in the model has been used as a tool for visualization and debugging. Additional pre-processing involved joint re-definition regarding system degrees of freedom (DOF). The interest in changeability lead to a parameterized model. A number of work cycles has been included in the model. They are introduced as translational joint motions between the actuators piston and cylinder part models.

3.2 Work area analysis

Several analyses have been performed up to date. Briefly presented here are the work area analysis and the basics of the model. In order to analyze the area (volume) that the tool center point (TCP) encircles an approach suggested by Makkonen [Makkonen 99] has been used. The X- and Z-actuator lengths (figure 7) were restricted by circle in circle constraints i.e. two force elements. These were active during the end of actuator lengths thus creating an end-stop between piston and cylinder part models. In order to get the wanted movement a 'vector force' was applied at the TCP. Unrestricted actuators would cause the force to pull the TCP in a circular pattern but the restrictions in combination with a Step-motion applied at the Y actuator created the box-like volume (figure 7).

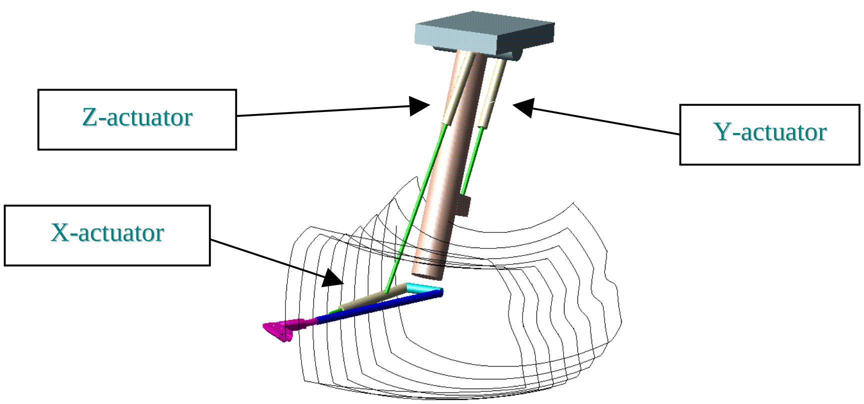

Figure 7, Work area [Johansson 00].

3.3 Flexible part models

The determination of eigenfrequencies as a decision support when improving design is an important issue. The control systems should be designed to avoid operation close to eigenfrequencies. The analysis of eigenfrequencies requires the introduction of elasticity in the robot model. One of the criteria when selecting parts to be flexible is that the selected part has major influence on the eigenmodes for the robot subsystem. In this particular case, the interest is in the lowest system eigenfrequencies.

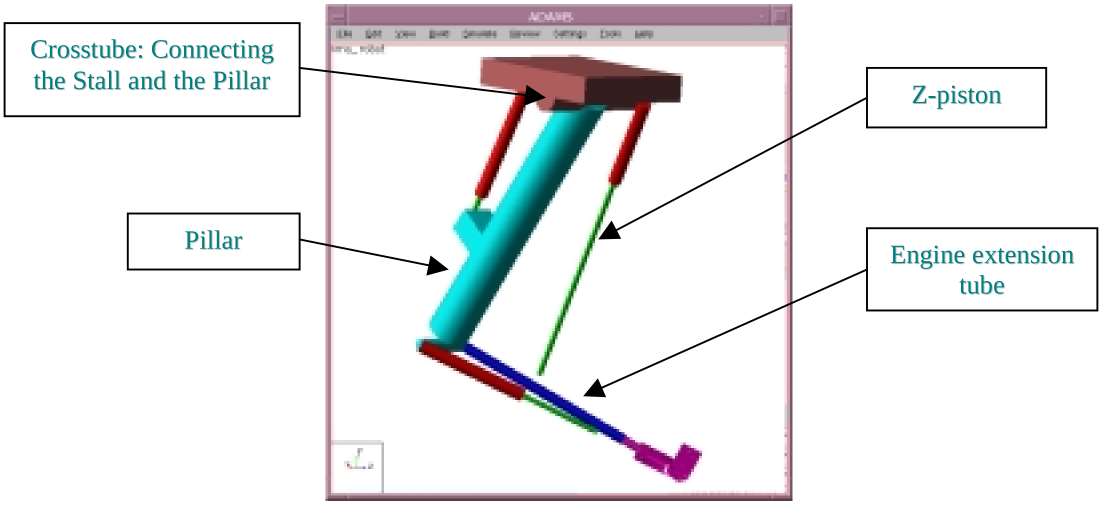

Figure 8, VMS™ modeled in ADAMS/View.

The following part models were selected to include elastic properties: the Pillar, the Z-piston, the Crosstube and the Engine extension tube (figure 8). The connections with other mechanism members were created by using dummy parts (figure 9). The reason for these part models to be chosen is that it was stated that they would have the lowest eigenfrequencies and that attempts to raise the system eigenfrequencies would therefore be directed towards these parts.

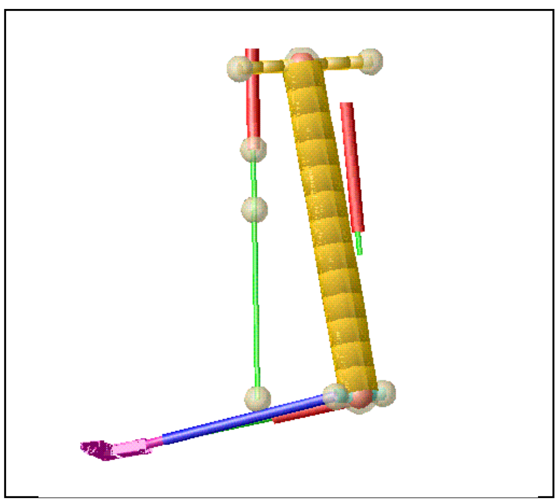

Figure 9, Flexible structure members introduced with dummy parts visualized as spheres.

The flexible part models were created using the 'discrete flexible link' command in ADAMS/View. The Pillar and the Crosstube part models have hollow circular cross sections and the Z-piston has a solid circular. The analysis has been made in time steps, with five seconds intervals, of one typical work cycle. This approach has been taken with the intent to compare the eigenfrequencies when the position of the robot subsystem is changing. The modeling of these parts is only at its starting point although some analyses have been performed. This has been done with the understanding that the model needs further refinement.

The analyses show the eigenfrequencies and modes for the structure with respect to simplifications made during the modeling process, a fact that is important to consider. The eigenmode assumptions concerning the part models turned out partly as expected.

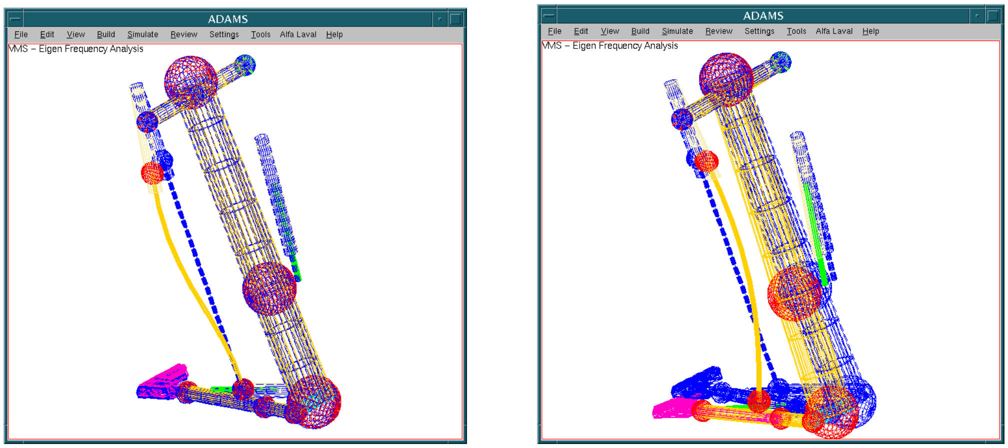

Figure 10, Result of eigenfrequency analysis (Mode 2 and 3). (Blue structure undeformed).

The results shown in figure 10 of part model eigenmodes give an understanding on where redesign would have the greatest impact. The analysis clearly showed what part model that had the lowest eigenfrequencies for the different positions.

4. Summary and Conclusions

The use of ADAMS™ in an agricultural robot setting is presented together with an approach towards a structured and systematic modeling and behavior simulation process model. An application example from DeLaval, i.e. the modeling and behavior simulation of it, is also presented. A conclusion that can be drawn from this work is that there is great potential in the proposed design procedure. An ADAMS model has been built and parameterized and realistic TCP movement cycles has been included in the model. Furthermore, some flexible part models have been introduced.
In the analysis performed so far, the robot subsystem model shows seemingly realistic behavior. However, the model has to be verified against measured values of the robots physical behavior.

5. Future Work

This work will continue with the introduction of the Stall part model. A finite elements (FE) model of the Stall is currently being developed. Refinement of MBS models containing flexible part models will also be carried out. The control system integration with the MBS model is also of priority. The PD process model needs further development towards a more comprehensive process description.

6. Acknowledgements

This work has been financially supported by the Swedish National Board for Industrial and Technical Development (NUTEK).

References:

[DeLaval] DeLaval AB, Tumba, Sweden, Company web site at http://www.delaval.com/

[Wittenberg 93] Wittenberg, G., “A robot to milk cows”, Industrial Robot / An international quarterly on industrial robot technology, Vol. 20 No5, pp.22-25, MCB University Press, 1993

[Hogeveen 96] Devir, S., Hogeveen*, H., Hogewerf, P.H., Ipema, A.H., Ketelaar-DeLauwere, C.C., Rossing, W., Smits A.C. and Stefanowska J., “Design & Implementation of a system for automatic milking & feeding”, Canadian Agricultural Engineering, vol. 38 No 2, pp107-113, Canadian Society of Agricultural Engineering, April 1996, (* Author)

[Pahl & Beitz 96] Pahl, G., Beitz, W., “Engineering Design: a systematic approach”, 2nd Edition, Springer-Verlag, London, UK, ISBN 3-540-19917-9, 1996

[Ertas & Jones 96] Ertas A. & Jones J.C., “The Engineering Design Process”, 2nd Edition, John Wiley & Sons, ISBN 0-471-13699-9, 1996.

[Ullman 97] Ullman, D. G., “The Mechanical Design Process”, 2nd Edition, McGraw-Hill, ISBN 0-07-065756-4, 1997

[Andersson 97] Andersson K., “Modeling and Simulation as a Control Means for Product Development”, 6th International Conference on Management of Technology, MOT97, Gothenburg, June 1997.

[Andersson 98] Andersson, K, Sellgren U., “MOSAIC - Integrated modeling and simulation of physical behavior of complex systems”, Norddesign ´98, Stockholm, August 1998.

[Makkonen 99] Makkonen, P., “On Multi Body Systems Simulation in Product Design”, Ph.D. Thesis, Department of Machine Design, Royal Institute of Technology (KTH), Stockholm, Sweden, May 1999

[Sellgren 99] Sellgren, U, “Simulation Driven Design – Motives, Means, and Opportunities”, Ph.D. thesis, Department of Machine Design, Royal Institute of Technology (KTH), Stockholm, Sweden, December 1999

[Johansson 00] Johansson, J., Andersson, K, “Modeling and simulation for concept evaluation of a milking robot prototype”, In Proceedings of NordDesign2000, pp85-95, DTU, Lyngby, Denmark, August 2000