Vibration analysis of a robotic milking system

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ABSTRACT

This paper deals with vibration analysis of an industrial application at DeLaval AB, the 'Voluntary Milking System™' (VMS). The system is part of the increasing automation of dairy farming and is just a part of an entire barn layout. This system has been divided into three subsystems: the stall, the robot and the control system. The eigenmodes as well as frequency responses at critical positions have been calculated both for the original system and for a modified system.

This application can be seen as an example of product with a high technological content and a complicated and complex structure with a large number of relations between subsystems. This type of complex products is difficult to handle in a product development process and the need for a systematic approach is obvious.

The approach given in this paper is based on treating the product as a composition of systems and subsystems. This is utilized as the base for a modular approach for using commercial CAE-tools for modeling and behavior simulation for evaluation of performance properties of product concepts. This approach has been used for modeling the stall and robot subsystem of the VMS. These modularized models have then been used as a base for vibration analysis.

Keywords: Design process, Vibration analysis, MBS

1 Introduction

In product development today the demands on the product, the product development team and the company are rapidly increasing. More demands have to be accounted for while the competition is getting harder on the global market. In engineering design much research work has been made and is still going on concerning how to create a common understanding or a theory of how to design good products, i.e. a design process model, e.g. [Hubka 84], [Andreasen 92], [Pahl 84]. One drawback of these works is that they are not addressing the issue of evaluation and prediction of product behavior as an integrated part of the product development process. This issue has however been addressed by Andersson [Andersson 97] who has suggested a general design process model (see figure 1) where the behavior modeling aspects have been integrated.

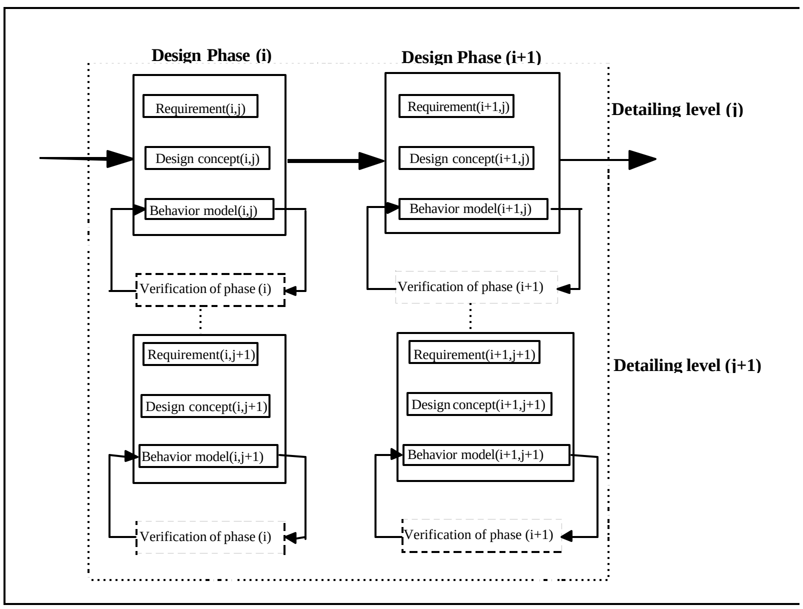

Figure 1. A general design process model [Andersson 97].

Today, most of the larger industries have their own process model for the product development, expressed either implicit or explicit. This process model describes for instance which activities to perform and what department those are responsible and what documents to produce as a decision support before deciding if the project should continue.

Support methods and tools are used as a natural part of the development work and are often used to integrate work in different departments. One reality today is the computer support area containing systems like, e.g. CAD (Computer Aided Design), FE (Finite Element) analysis, MBS (Multi Body Systems) analysis and PDM (Product Data Management). These systems can support many design tasks during product development and also store results for later retrieval and revisions.

Current commercial software for behavior modeling such as FE and MBS software are often focused on the component level e.g. with analysis such as strength calculations and form optimization. These commercial software tools have a good functionality, e.g. with associativity between CAD and FE models at the component level. On the other hand they have a much weaker support for modeling at a system or product level, and thus restricting engineers to model and simulate behavior of the assembled product.

However, the proposed design process model in figure 1, actually addresses this problem. This approach has been used in the MOSAIC project [Sellgren 98] and is based on treating the product as a system that can be divided into smaller systems, subsystems. If we identify and model the connections, interfaces, between these subsystem s, then we can model the subsystems separately and then use them for assembling a model of the total system, see [Andersson 99], [Sellgren 98] and [Sellgren 99].

2 The DeLaval 'Voluntary Milking SystemÔ' (VMS)

During the last few years DeLaval has been working with the development of a new product concept in diary farming, see figure 2. As the name implies this system allows the cows themselves to decide when they want to be milked introducing a larger flexibility. The system is part of the increasing auto mation of dairy farming and is just a part of an entire barn layout. Compared to other traditional type milking concepts the VMS has many advantages e.g. work reduction. The target size farm has a herd with at least 60 cows [Wittenberg 93].

Figure 2. The 'Voluntary Milking SystemÔ' (VMS).

To enable modeling and performance simulation of this according to the approach developed in the MOSAIC project, this system has at top level, been divided into three subsystems: the stall, the robot and the control system. Then we have focused on the robot and divided this further into subsystems. The approach here has been to model the robot subsystems separately and thereafter make a number of configurations of submodels describing the entire robot (sub) system for different evaluation and prediction purposes. The structure of the milking robot is shown in figure 3.

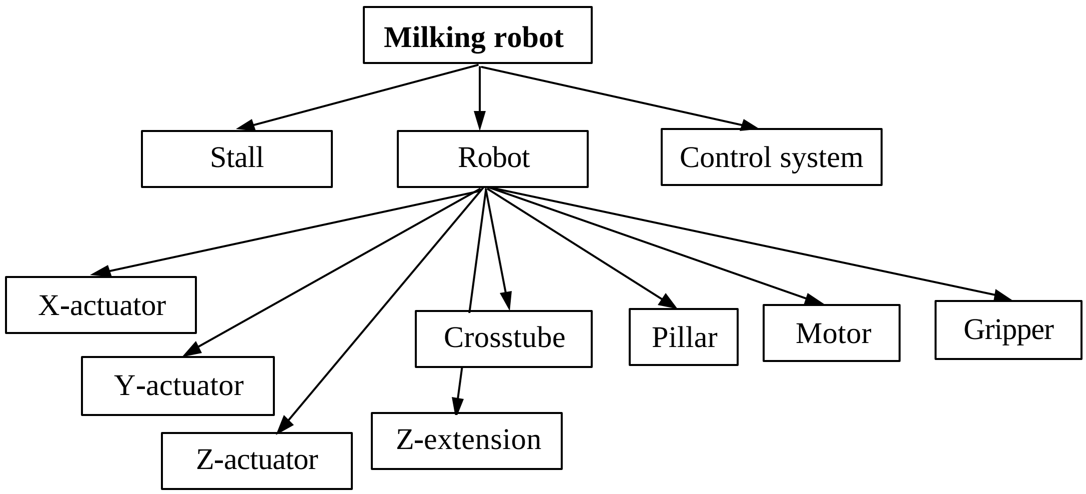

Figure 3. Product structure of the 'Voluntary Milking System™'

3 Modularity of the milking robot

One of the ideas with the MOSAIC project as well as the design process model in figure 1 was to enable behavior models to be configured of subsystem models, which are accurate enough for the actual analysis demands. For the studied application with the milking robot we have identified the different interfaces between parts, which are illustrated in the topological connection graph shown in figure 4.

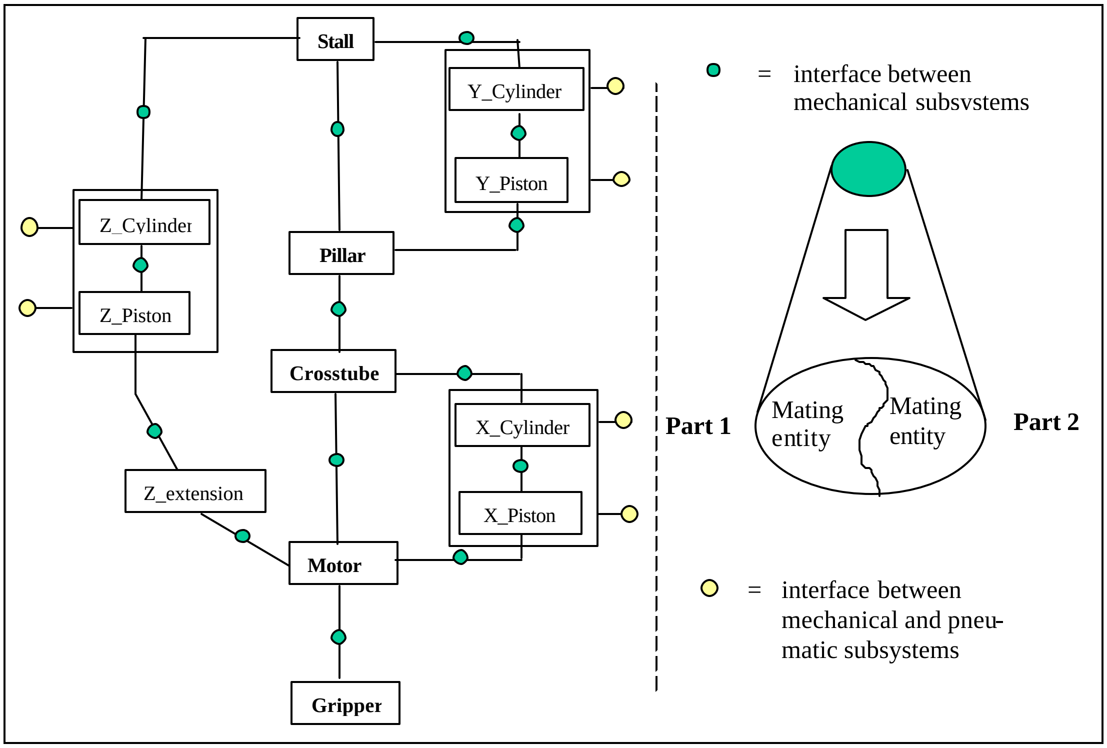

Figure 4. Topological connection graph of the robot subsystem.

This graph also shows that an interface is a connection between two mating entities belonging to different parts. This means that when we model the parts in the robot assembly we must pay special attention to modeling the mating entities such that they can be part of a wanted interface, e.g. a revolute joint requires a position and a rotation axis on both parts.

3.1 Modeling of subsystems

The origin of this modeling example is geometry models that have been modeled at DeLaval AB. These have been translated and imported into the I-DEAS CAE system (from EDS Inc.) where they have been reassembled. Then we have used I-DEAS to create a mechanism model, i.e. adding joints and motion constraints to the assembly model. Thereafter this mechanism model has been transferred to the ADAMS MBS system (from MSC Software Inc.), but without any geometric description of the parts. Simplified geometry for the parts has been created in ADAMS. Figure 5 shows a detailed geometry model of the robot assembly in I-DEAS and corresponding assembly in ADAMS.

Figure 5. An I-DEAS (left) and corresponding ADAMS model (right) of the robot.

Next step is to identify the interfaces and mating entities that we have to model. In this case we have chosen to model the mating entity as a dummy part in ADAMS. This means that each part in the topological graph in figure 4 is locked to at least two mating entities and the joints are defined between these mating entities. Figure 6 illustrates some of the identified interfaces of the robot.

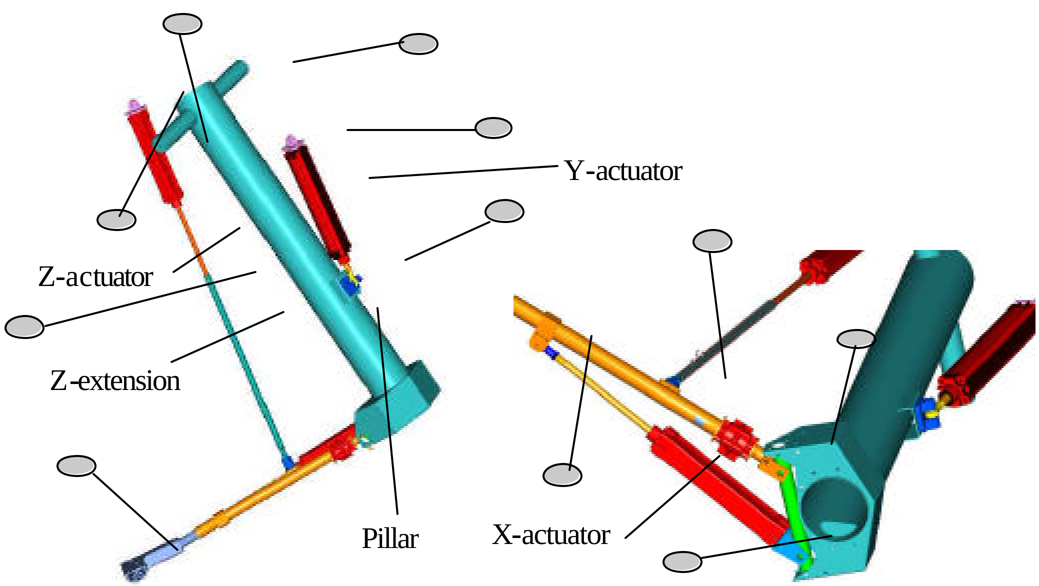

Figure 6. Some of the identified parts and interfaces in the robot model.

5 Vibration analyses

The problem area that we will cover in this paper is problems with vibrations and excitations of eigenmodes of the robot. Of specific interest here is to study eigenmodes and responses of the Z-actuator (with extension). Configuration of system models is an interesting question here; what configuration is sufficient for studying eigenmodes and frequency response in the total system of robot and stall?

5.1 Eigenmodes of the robot

To start with we need to determine the eigenmodes of the robot. The part of the robot that we have recognized as the most critical part is the long and slender Z-piston with the piston extension. For this purpose we have configured a robot model of a mixture of flexible and rigid parts. The actuators have been modeled as a spring-damper element using an assumption that the air is kept in the actuator and the valves are all closed. Further we assume that pressure areas are equal on both sides of the piston and that the piston is approximately in the middle of its stroke. Based on these assumptions we have used the following approximations for spring stiffness K and damping C.

$K = 4.5$ N/mm

$C = 0.03$ Ns/m

The Z-piston and piston extension have both been replaced with elastic parts being modeled with beam elements in ADAMS. For this purpose we have used the previously identified interfaces and the modeled mating entities (dummy parts). We have then modeled the robot in its start position and calculated its eigenmodes at this position. Figure 7 shows the assembled ADAMS model where the mentioned rigid parts have been replace with elastic parts. In figure 8 and 9 four eigenmodes for the Z-actuator are illustrated.

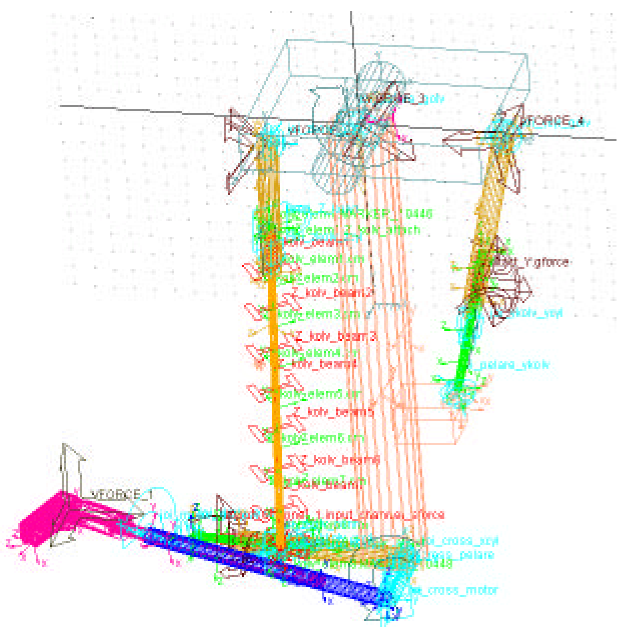

Figure 7. The assembled robot model for eigenmode analysis.

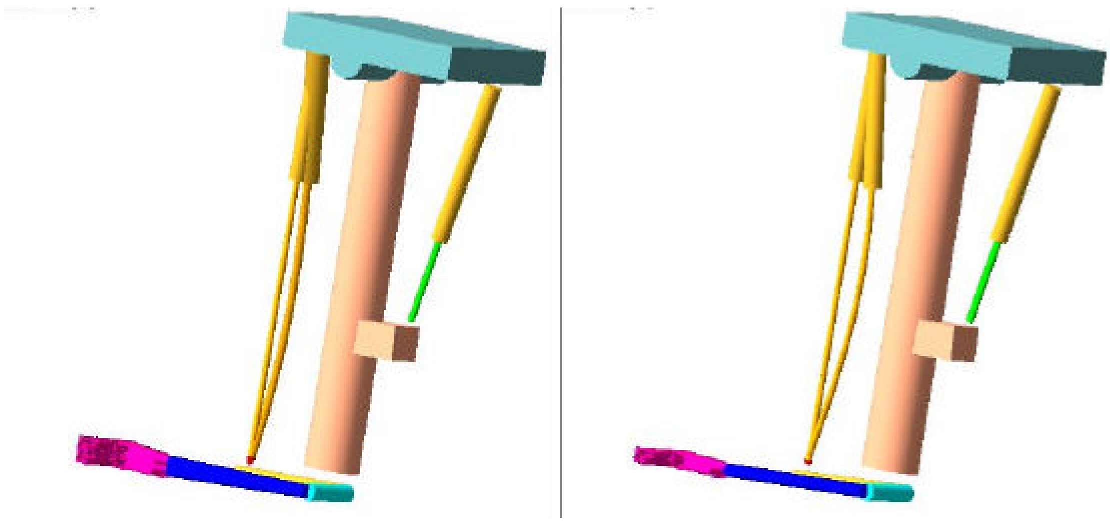

Figure 8. The first two eigenmodes of Z-actuator.

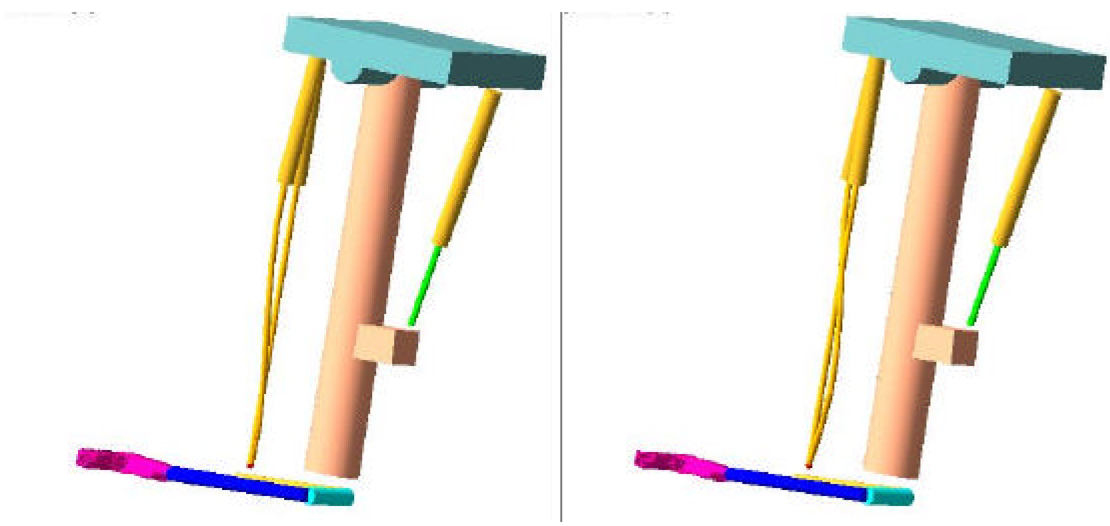

Figure 9. Eigenmodes 3 and 4 of Z-actuator.

Next thing to study is what response we get in the Z-actuator when we apply a sinusoidal force at the X-actuator and make a vibration analysis. The purposes here are to identify if any of the responses are amplified at the eigenfrequencies shown in figure 8 and 9.

Based on the modular modeling approach discussed earlier we can configure two system models for this investigation.

Model 1: Robot subsystem only, where Z-piston and piston-extension are modeled as flexible beam elements.

Model 2: Robot subsystem with stall, where robot is modeled as in model1 and the stall is modeled in an FE program and imported as a static condensation of the FE model.

The idea here is to find what influence the stall has on the responses at the X-actuator. If the influence is of minor importance then we can use the simpler model without the stall.

5.2 Vibration analysis of robot

The first system model is a model of the robot subsystem with a configuration of rigid and flexible parts, where the Z-piston and Z-extension have been modeled as flexible parts using beam elements in ADAMS. To this model we have added a sinusoidal disturbing force at the X-actuator, see figure 10.

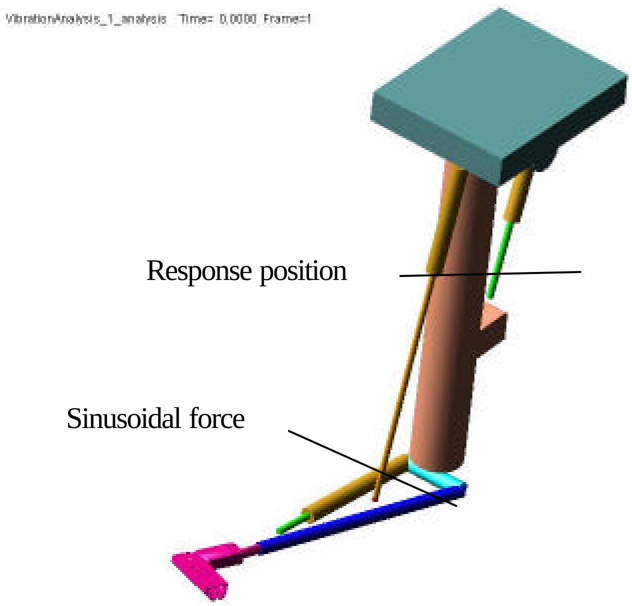

Figure 10. Illustration of where the force is applied and where the response is measured.

Vibration analysis has then been performed using ADAMS/Vibration where the acceleration response has been measured at the Z-actuator and the X-actuator (as a reference). The results of this analysis are shown in figure 11 and 12.

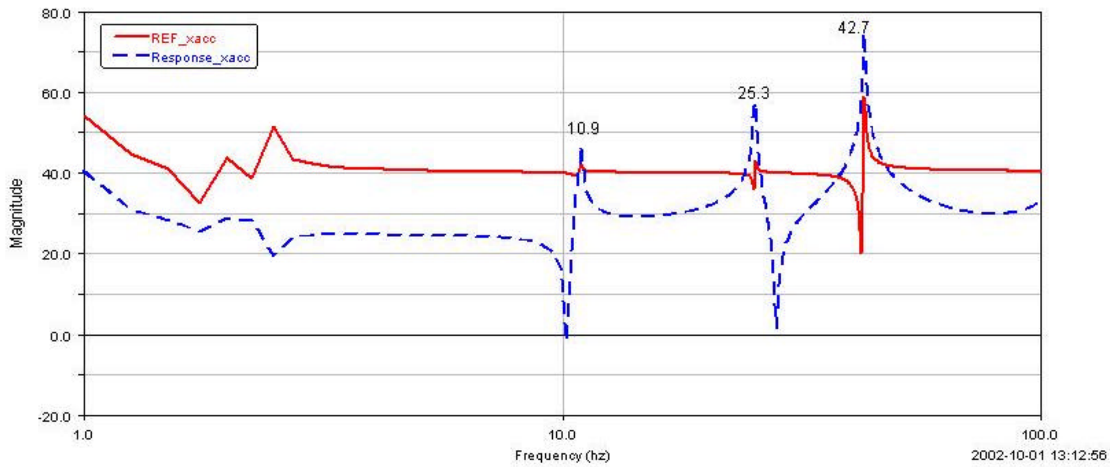

Figure 11. Acceleration response at Z-actuator in x direction.

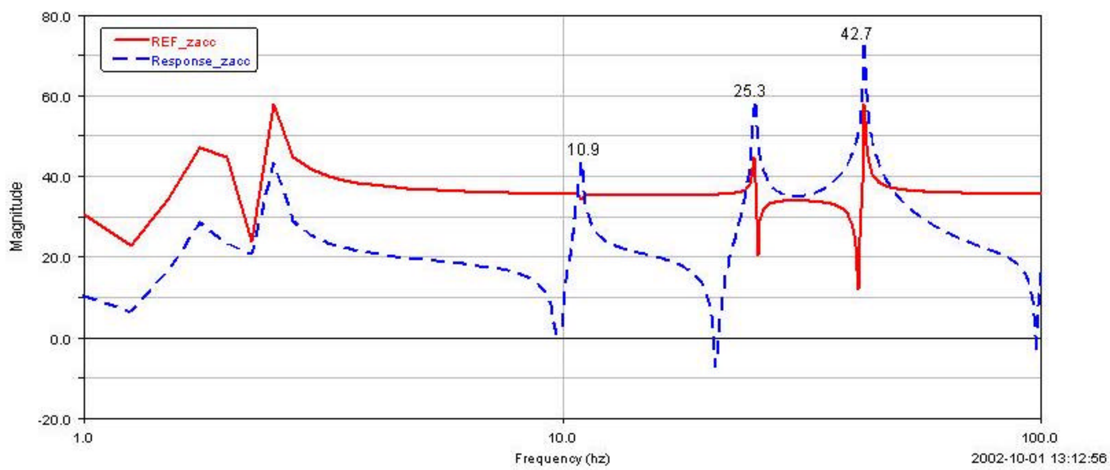

Figure 12. Acceleration response at Z-actuator in z direction.

The responses that we can see in figure 11 and 12 correspond to the first three eigenmodes of the Z-actuator that are shown in figure 8 and 9.

5.3 Vibration analysis of robot and stall

The second system model is a model of the robot subsystem together with the stall where the robot model are the same as in previous section and the stall is modeled in a FE system and imported as a static condensation of the FE model, see figure 13. To this model we have added a sinusoidal disturbing force at X-actuator in the same way as we did earlier.

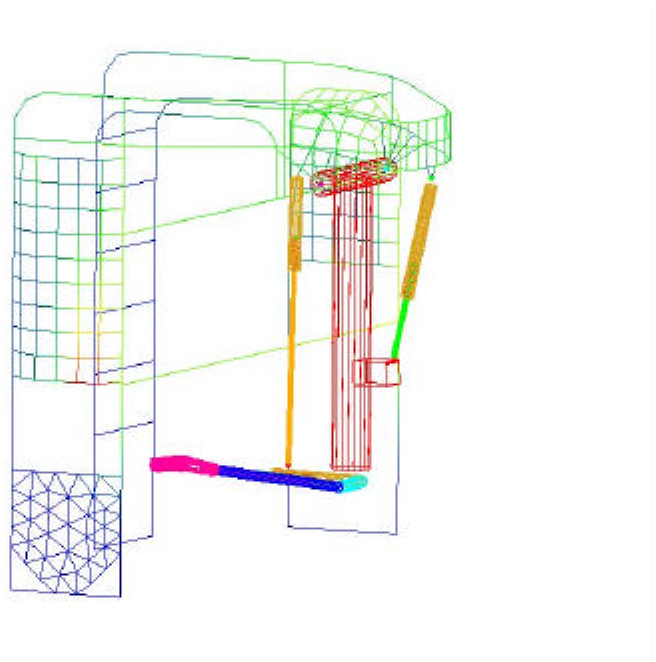

Figure 13. Model of robot with stall.

A vibration analysis has then been performed using ADAMS/Vibration and the acceleration response has been measured at the Z-actuator and the X-actuator (as a reference). The results of this analysis are shown in figure 14 and 15.

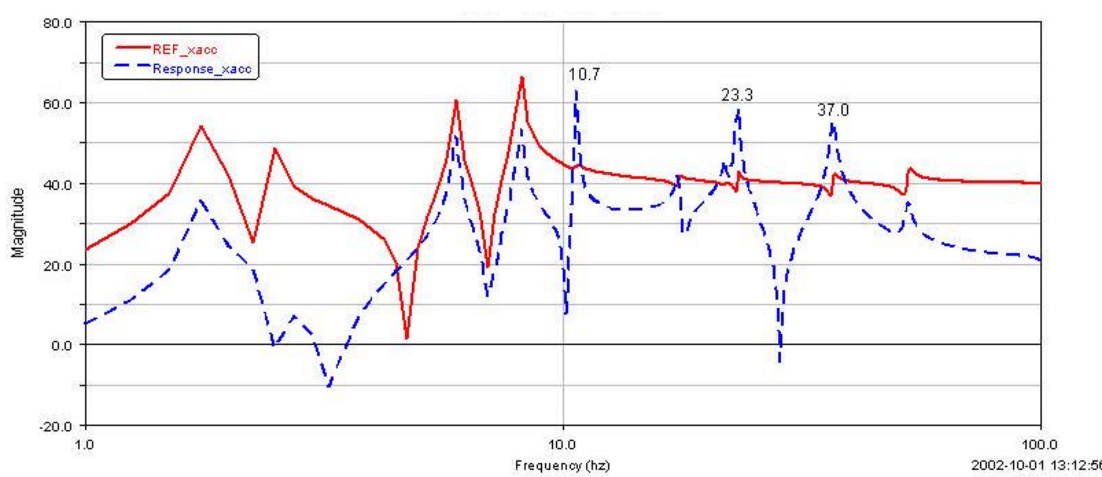

Figure 14. Acceleration response at Z-actuator in x direction.

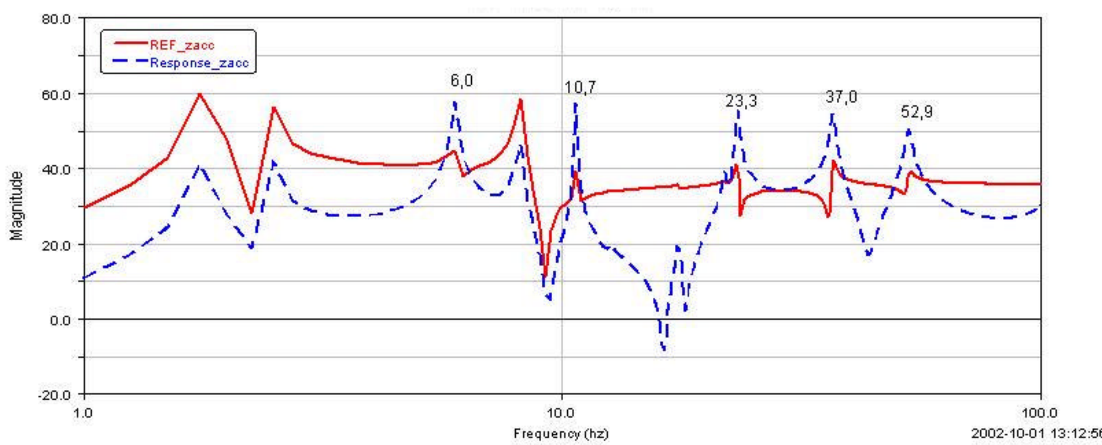

Figure 15. Acceleration response at Z-actuator in z direction.

In the curves plotted in figure 11-12 and 14-15 we can see that the response just above 10 Hz is present in both model configurations. This response corresponds to the first eigenmode of the Z-actuator with Z-extension and this is what we want to eliminate or move to a higher level such that it is harmless for the system. I this case we want to move this eigenfrequency above 15 Hz.

5.4 Modification of the robot subsystem

The goal with this modification is to attenuate or move frequency responses in the interval of 10-15 Hz. The question here is what model configuration to use for evaluating design changes. From the curves plotted in figure 11-12 and 14-15 we can see that the stall seems to have very little impact on responses in this interval. However, there is a response, originating from the stall at about 6 Hz and it can be interesting to study what impact design changes has on this response as well. Because of this response at about 6 Hz we will use model configuration with both robot and stall (model 2) for evaluating effects from design changes.

5.4.1 Modification of the Z-extension

The first modification that we are to analyze is the modification of the Z-extension. In this analysis we have changed the Z-extension from a solid circular beam with a diameter of 18 mm to a circular beam with diameter 40 mm.

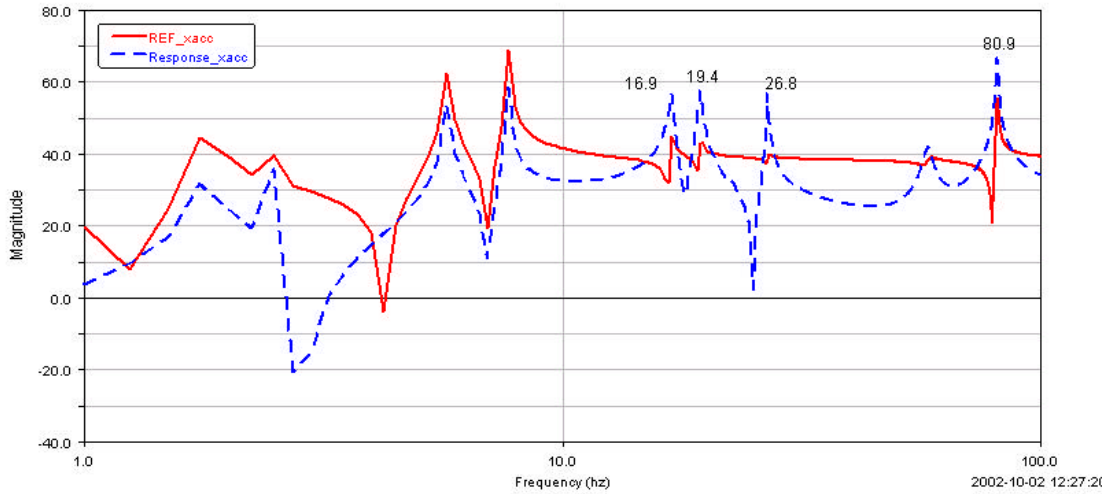

Figure 16. Acceleration response at Z-actuator in x direction.

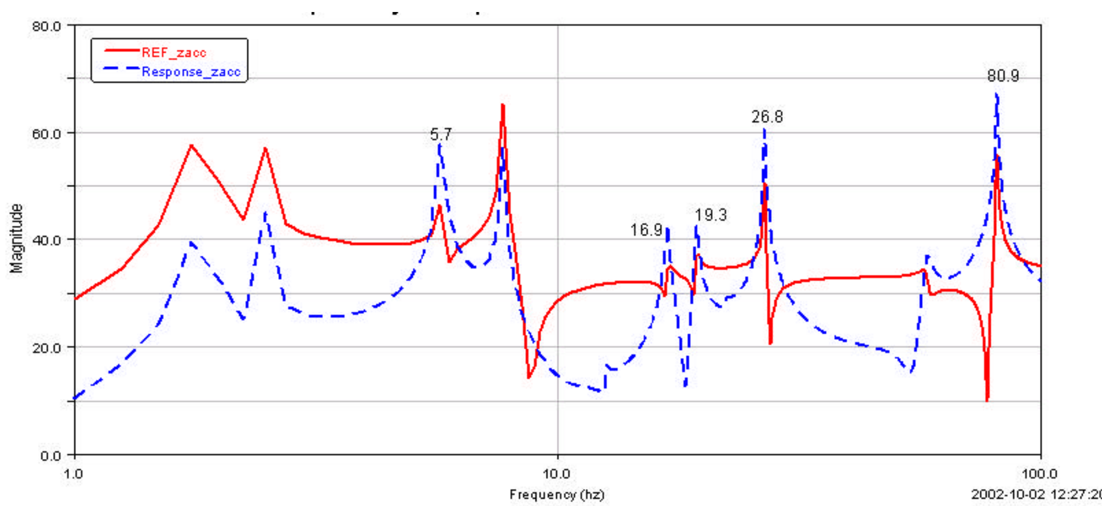

Figure 17. Acceleration response at Z-actuator in z direction.

The effect that we aimed for with this modification of the Z-extension was to eliminate the response at ca 10-11 Hz and this has been accomplished for both x and z directions. The response peak has been move to 16.9 Hz in both directions.

5.4.2 Modification of Z-actuators upper joint position

The other modification for eliminating the response at 10-11 Hz is to move the upper joint position of the Z-actuator. This position has been moved 150 mm in the direction of the Z-actuator that it has in the start position. This means that the stall has been extended corresponding distance and as a first approximation we use a rigid body for modeling this extension. In fact to have the desired effect this extension should be rather stiff if this modification should be meaningful. The results of a vibration analysis with the same data as earlier, gives the results shown in figure 17 and 18.

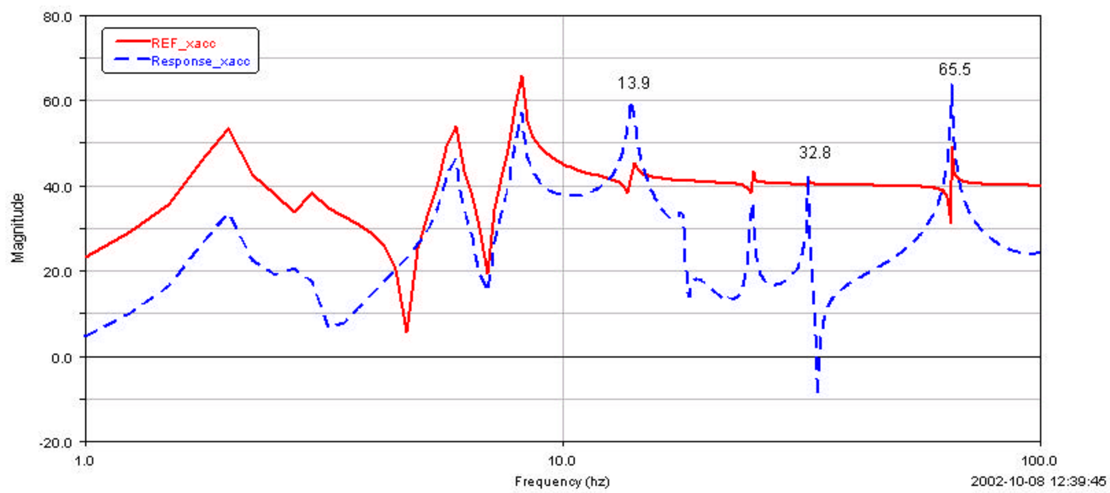

Figure 17. Acceleration response at Z-actuator in x direction.

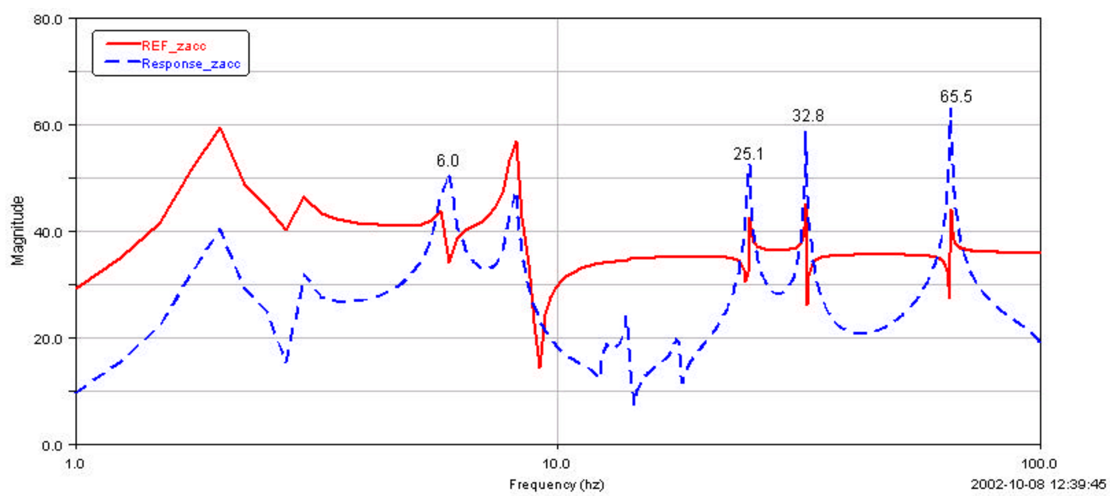

Figure 18. Acceleration response at Z-actuator in z direction.

In figure 17 and 18 we can see that we have reached a good marginal for the response in z direction where the response between 10 and 25 Hz have been attenuated. However this is not the case in with the response in x direction. In the x direction we still have a response at 13.9 Hz

5.4.3 Obtained effects of modifications

The goal with these modifications was to attenuate or move frequency responses in the interval of 10-15 Hz. The model configuration we choose to use was model 2, a partly flexible robot with a flexible stall for evaluating design changes. From the analysis we can conclude that the first modification, changing the diameter of the Z-extension, has the greatest effect on the frequency responses in the interval of 10-15 Hz. This modification is probably also easier to implement since it doesn't change the moving pattern for the robot. An alternative can be to combine the two modifications since moving the joint position also have a positive effect on frequency responses in the actual interval. However this will change the moving pattern of the robot and need more work to implement.

The effects on the response, originating from the stall at about 6 Hz was not significant. A conclusion of that is that we could have used model 1, the partly flexible robot, for evaluating design changes instead.

6 Summary, conclusions

Modern products tend to get more complicated and it is harder to get a holistic view of its behavior. Modern CAE tools can support the designer to obtain at least to some extent, this holistic view. This requires strategies for how to use commercial CAE-tools for modeling and behavior simulation for evaluation of performance properties of product concepts. The strategy presented and used in this paper in based on the one proposed by Andersson [Andersson 97]. This has been followed and applied on the industrial example from DeLaval, the 'Voluntary Milking System™' (VMS).

The idea of treating the product as a system that can be divided into smaller subsystems has been illustrated on one of the subsystems, the robot subsystem. For this subsystem we have identified some of the mating entities and interfaces that are needed for configuration of behavior models of the robot subsystem.

The approach of configuring system models for different analysis purposes have been used for calculation of eigenmodes and frequency responses for the VMS system. For these analyses two main configurations have been used; one with a partly flexible robot and one where this robot model has been connected to a flexible stall. These configurations have been used to illustrate how this approach can be used for tuning the system performance by avoiding frequency responses in specific frequency intervals.

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