Simulating Hydraulic-Driven Mechanical Systems

Dr.-Ing. Martin Piechnick

Mannesmann Rexroth GmbH

97813 Lohr am Main (D)

Tel.: 0049 9352 18-3549

Fax.: 0049 9352 18-3299

1 Introduction

Computer-aided system simulation has become a well established and commonly used tool when projecting hydraulic and electro-hydraulic drives. Thanks to the use of modern software tools in the development stage it was possible to considerably improve parts of important drive characteristics such as efficiency, energy balance, dynamics and control accuracy. Cost and time consuming test series in the test field can often be supplemented or even replaced by computer simulation. Increasing personnel costs call for a minimization of commissioning times and thus for a reliable system optimization at an early development and design stage. Also here, calculation programs provide assistance to an extent which was inconceivable still some years ago.

Most of the modern simulation programs for the analysis of hydraulic drive systems are based on a graphical and block-oriented model editor. Thus, the structure of the computer model is not realized by the input of mathematical equations but by means of an illustrated representation of the hydraulic circuit diagram in line with practice. This circuit diagram can often be supplemented by open and closed loop control signal transfer blocks. The generation of the descriptive equation system is carried out in the background and can optionally be parameterized via menu-guided data input (e.g. nominal flows, masses, cylinder dimensions, etc.).

With the help of program-integrated signal generators, system inputs such as counterforce characteristics, command value signals and control voltages can be simulated and the characteristics of the simulated system be examined at almost any working point and process sequence.

2 MOSIHS - Modular simulation of hydraulic systems

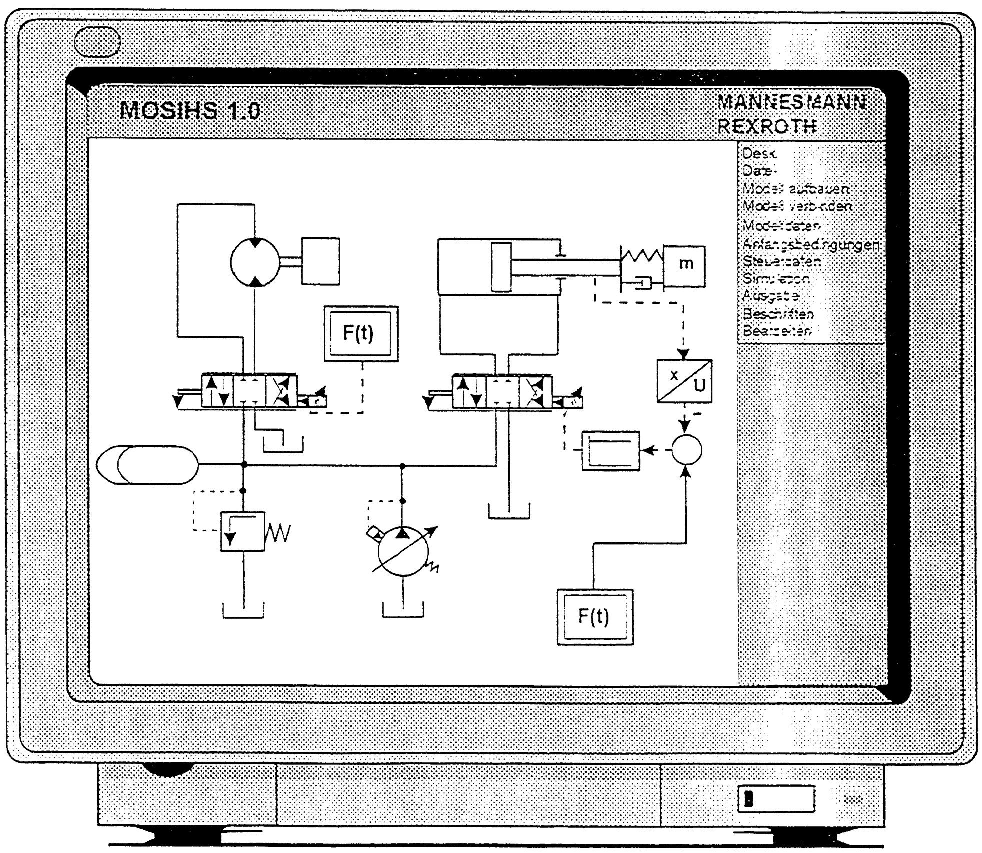


Fig. 1: Graphical model editor of the MOSIHS simulation program

An example of this type of simulation system is the MOSIHS (modular simulation of hydraulic systems) program. MOSIHS was developed by MANNESMANN REXROTH several years ago and since then has been used in many applications in the field of development and projecting of systems. Its graphical model editor (fig. 1) is based on modules comprising more than 100 individual items from the technological areas of hydraulics, open and closed loop control technology, mechanics and sensorics.

The model library is going to be extended by functional elements from pneumatics and servo pneumatics (fig. 2). It is just the field of closed loop controlled pneumatics where an optimization of the drives is particularly difficult due to the complex thermo-dynamic properties of the air and due to the unfavourable relationship between drive and friction forces. Simulation programs in line with practice could provide valuable assistance here.

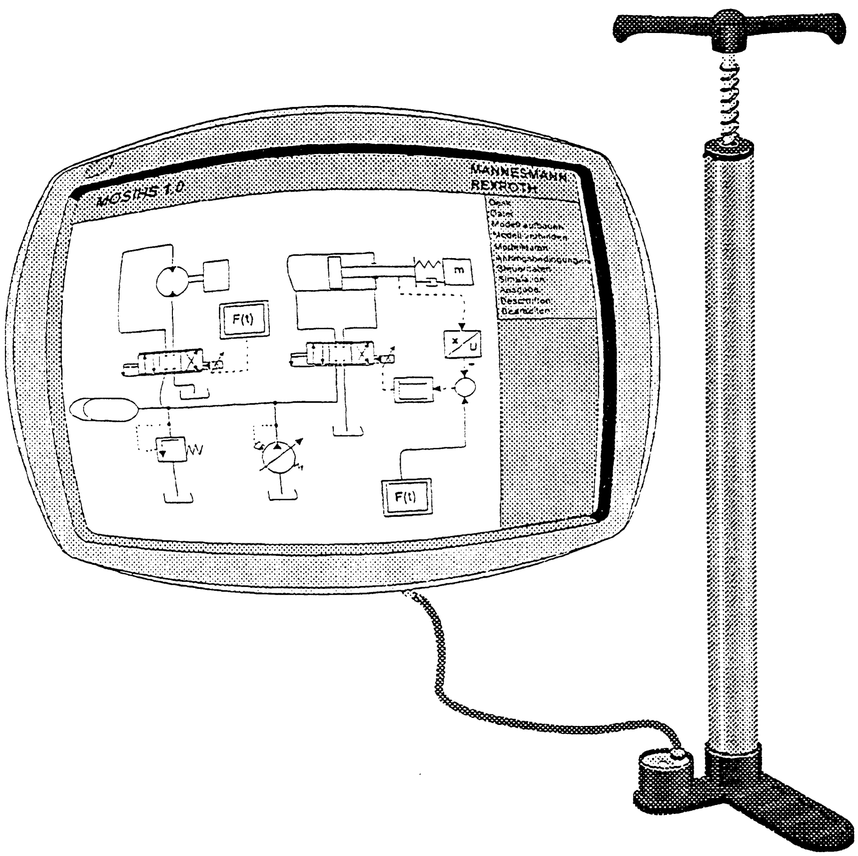


Fig. 2: Extension of MOSIHS by functional pneumatic elements.

MOSIHS can be used to simulate electro-hydraulic systems with any number of individual axes. The influence of various systems components, circuit concepts, input variables or control structures on the characteristics of the drive can be examined within a few seconds.

3 Interfacing of MOSIHS and ADAMS - simulation of hydraulically driven multi-body structures

Hydraulics are often used as drive technology in machines and systems, where the transmission of forces is accomplished via complex kinematic structures. Classical examples of this can be found in the fields of mobile hydraulics, testing technology, handling technology, robotics, motion technology, aviation and space technology or the general machinery construction sector.

The demand for ever shorter development times and for optimization of the drives for special applications makes it more and more necessary to examine the characteristics of such mechanical arrangements in simulation studies. In connection with this, block-oriented simulation programs soon reach their limits, since the free definition of plane or three-dimensional structures requires completely different mathematical simulation approaches (multi-body dynamics) and solution algorithms.

ADAMS - one of the most efficient multi-body simulation programs world-wide - offers excellent functionalities for the simulation mechanical systems, however, the simulation of hydraulic transmission units is only possible by the use of mathematical functional modules or by free FORTRAN programming of individual sub-programs. As a result of this highly abstract solution, the investment of time for the simulation is very high - especially when simulating electro-hydraulic drives as close as possible to reality.

In order to enable the simulation of hydraulic-mechanical systems nonetheless in a practice-oriented and user-friendly manner, an interface between MOSIHS and ADAMS was developed within the framework of a cooperation between Mannesmann Rexroth and Mechanical Dynamics, which provides the combination of the individual program-specific capabilities and features.

This interface is limited to the continuos exchange of system variables, which are of importance in both partial system - hydraulics and mechanics. The computation of mechanics is carried out by ADAMS, with the actual forces and moments for each simulation step being supplied by the MOSIHS program, which works in parallel. MOSIHS, in turn, receives information on the displacement and speed of the mechanical drive elements. Thus, the volumes of pressure chambers can be updated and hydraulic time constants can be re-calculated. In order to simulate complex open and closed loop control processes, ADAMS can transfer any required system variable to MOSIHS (e.g. rotary angle for the implementation of closed loop angle controls).

On the basis of an example of a simple, hydraulically operated, four-bar linkage, fig. 3 illustrates the subdivision of the entire model into a mechanical (ADAMS) and an electro-hydraulic partial system (MOSIHS). The position of the drive cylinder is closed-loop controlled.

All the mechanical output elements - the piston rod and the cylinder barrel included - are simulated in ADAMS. The simulation of the valves and the structure of the closed control loop is carried out in MOSIHS. The characteristics of the cylinder are processed by MOSIHS exclusively via the two (piston rod-dependent) chamber volumes. The actual pressure forces are transferred to ADAMS and taken into account in the corresponding motion equations. ADAMS permanently reports changes in the relative movement between cylinder barrel and piston rod so that MOSIHS can update the chamber volumes and thus the relevant time constants required for the pressure build-up equations.

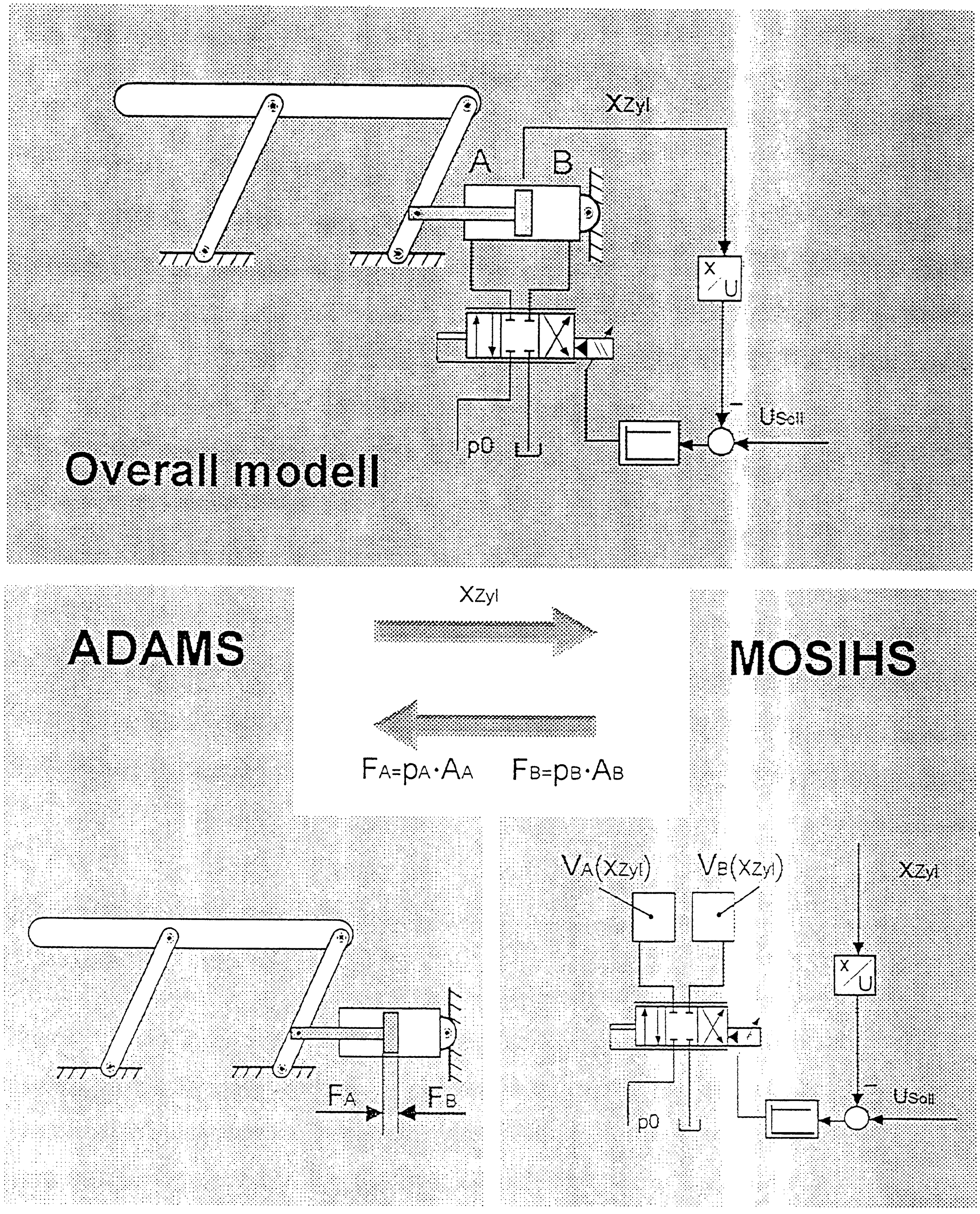


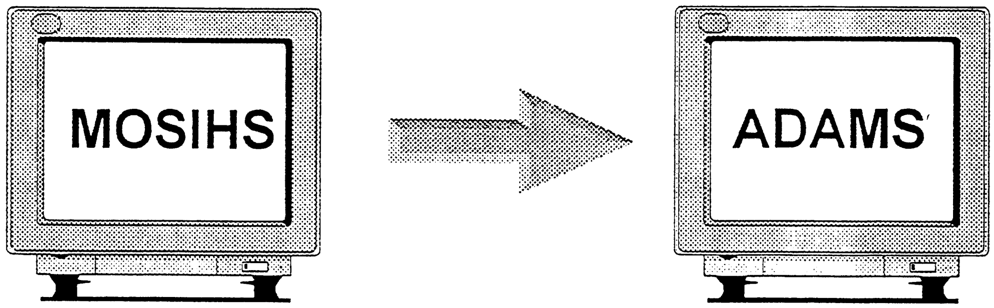
Fig. 3: Subdivision of the overall model into partial structures for MOSIHS and ADAMS

Fig. 4 shows the practical procedure when creating linked simulation models. In general, MOSIHS output variables are forces or torques/moments, which are calculated as outputs of certain model blocks (e.g. summators). These outputs (e.g. summator 4) are assigned to certain VARVAL elements in ADAMS. This assignment is via the ADAMS ID number. By activation of USER FUNCTION 100, the corresponding variable can take advantage of the contents in the MOSIHS output. With the help of a SINGLE COMPONENT FORCE, the force in the ADAMS model can be generated, the amount of which communicates with the contents of the previously generated VARVAL variable.

The ADAMS results are also fed back through VARVAL STATEMENTS. VARVAL contents calculated by ADAMS are defined as inputs to certain MOSIHS blocks (e.g. cylinder positions or speeds). An additional generation of a REQUEST using USER FUNCTION 100 is required for the data transfer between ADAMS and MOSIHS.

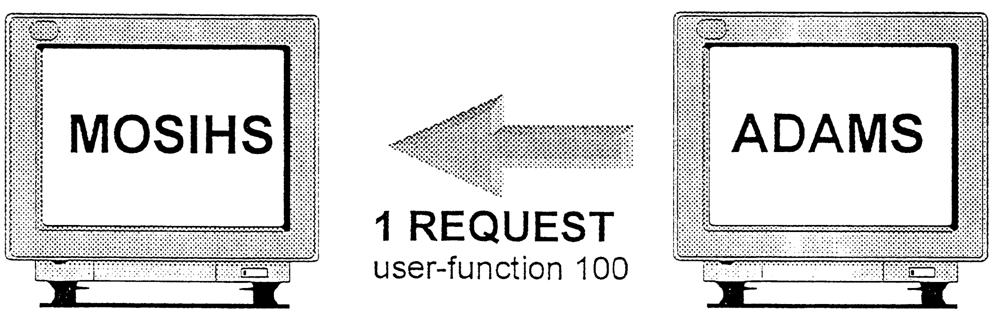
Clock-pulsing of the simulation steps is carried out via MOSIHS, as the calculation of hydraulic models often requires the consideration of very small time constants and large natural frequencies. Both programs use their own numeric integration procedures. The resulting mathematical separation of the partial systems generally improves the integration stability.

As the programs were solely changed with regard to their data transparency, the high degree of specialization inherent in both systems was maintained. Thus, it was possible to combine the know-how and experience gained by the development partners Mannesmann Rexroth and Mechanical Dynamics over many years. The developed simulation linkage opened up completely new possibilities for the development of electro-hydraulically operated mechanical structures. Systems, which could hardly be simulated so far, can now be simulated and subjected to detailed analyses.



Block type	Block no.	Assigned to ADAMS-ID.
Summator	4	8
Constant	12	21
Signalprocessor	2	3
Summator	5	32

ADAMS-ID.	VARVAL (user-function 100) →	Single component force
8	1	function: VARVAL(1)
21	2	function: VARVAL(2)
3	3	function: VARVAL(3)
32	4	function: VARVAL(4)



Block type	Block no.	Input type	Assigned to ADAMS-ID.
Cylinder	1	Piston stroke	22
Motor	11	Rotary angle	14
Factor	9	Input	10
Cylinder	2	Speed	3

ADAMS-ID.	VARVAL-no.	function (example)
22	1	DX(MAR4,MAR7)
14	2	AX(MAR2,MAR3)
10	3	ACCX(MAR1,MAR5)
3	4	VX(MAR11,MAR25)

Fig. 4: Assignment between MOSIHS and ADAMS data

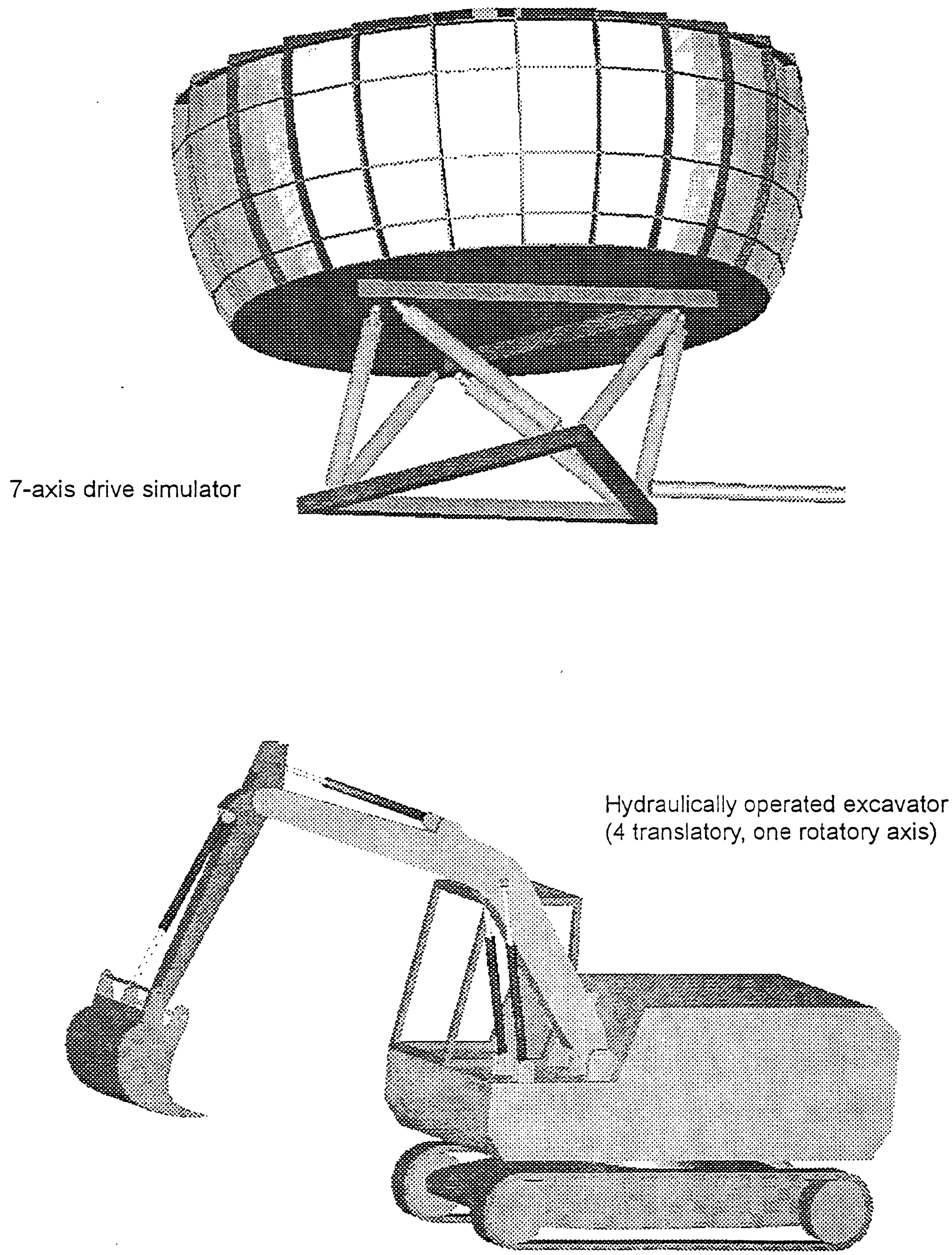


Fig. 5: Practical examples of combined MOSIHS/ADAMS simulations

Fig. 5 shows two examples, which have been put into practice using combined MOSIHS/ ADAMS simulations. The first example referred to a drive simulator driven by means of seven hydraulic axes. Here, examinations focused, amongst others, on the suitability of various axis controller concepts and the dynamic behavior during the transmission of forces to the vehicle under test. The second example dealt with oscillatory characteristics of the coupled linear axes in a bucket excavator.

Numerous other fields of application are conceivable:

- Mobile hydraulics: Construction machinery, excavators, agricultural machinery, etc.
- Closed loop control technology: Hydraulically operated, coupled multi-axis controls
- Aviation and space technology: Landing gears, flap, rudder and engine controls
- Automotive technology: Hydraulically damped running gear, steering systems, etc.
- Hydraulic components: Rotary groups of axial and radial piston pumps
- Motion technology: Stage technology, motion platforms, handling equipment
- Machinery construction: Machine tools, plastic processing machinery, etc.
- Plant construction: Hydraulically operated plants for foundries, steelworks, rolling mills, etc.
- Handling technology
- Civil engineering: Sluices, gates, lifting gear, off-shore systems

4 Consideration of flexible machine components

The interface available in ADAMS to several common FEM systems also allows to consider flexible structures. Together with MOSIHS interfacing, the influence of, for example, bending oscillations with a low frequency on the drive characteristics can be analysed. Especially with closed loop controlled systems, these influences often cause considerable stability problems. With the help of specific simulation studies it would be possible to work out alternative closed loop control or design concepts, which could contribute to an improvement of system properties.

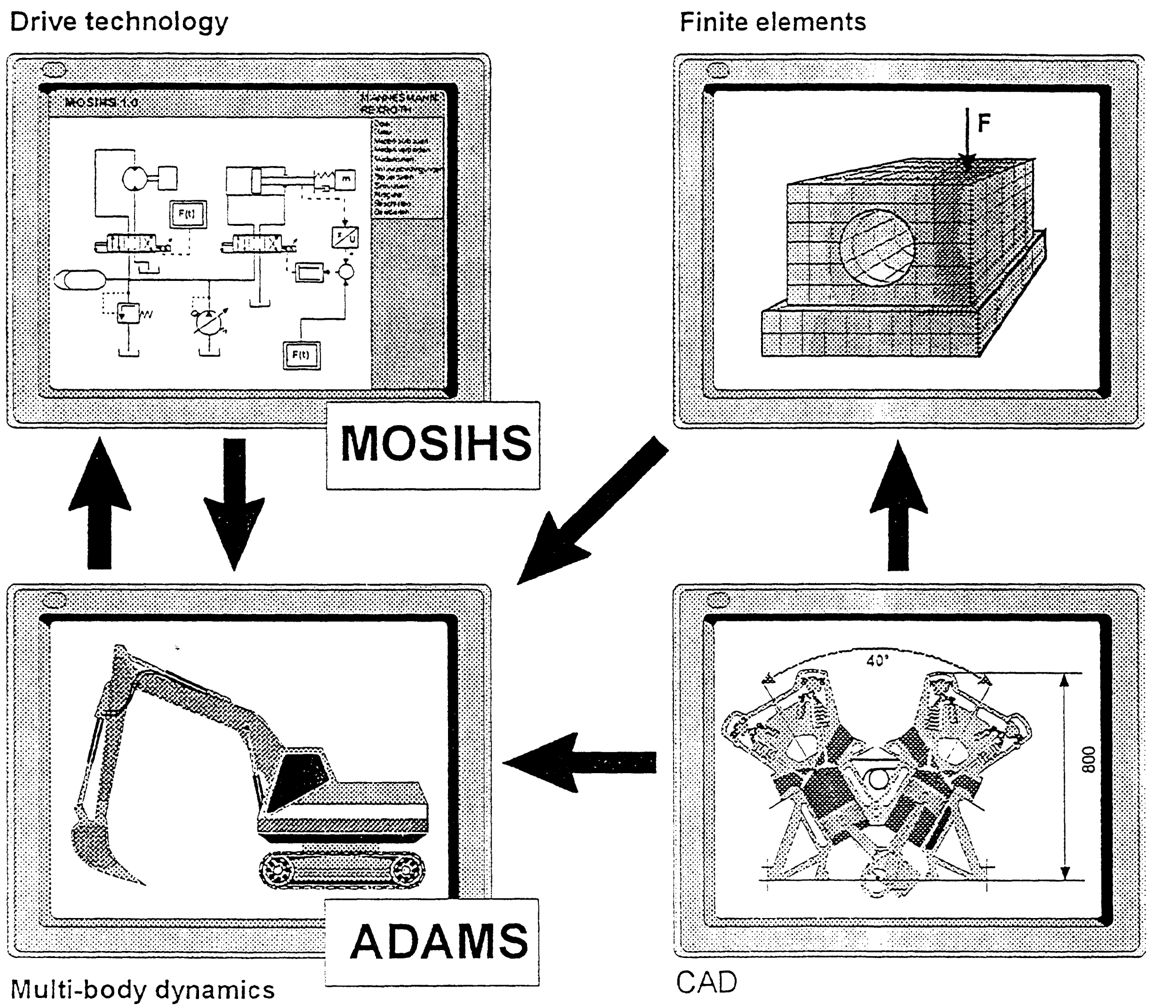


Fig. 6: Interfaced simulation taking into account drive and closed loop control technology, multi-body dynamics and structural mechanics (with CAD interface for a simplified model generation).

The calculation expenditure for combined MBD, FEM and drive technology simulations is considerable. But by now, the efficiency of modern hardware systems has reached a level, where this type of calculations appears to be useful. Fig. 6 illustrates the concept of an interdisciplinary system analysis. Here, CAD programs were additionally interfaced in order to accelerate the generation of three-dimensional MBD and FEM models. ADAMS as well as numerous FEM systems are fitted with suitable CAD interfaces which provide quick access to existing designs.

5 Summary

Interfacing of different simulation programs is a simple possibility of simulating and calculating systems of high complexity. The structure of the individual, interconnected programs is maintained so that the implementation work can be limited to the creation of suitable interfaces.

Taking this combination of the two programs MOSIHS (simulation of hydraulic systems) and ADAMS (simulation of complex multi-body structures) as an example, this paper is to present a comfortable and user-friendly possibility of analysing hydraulically driven mechanical systems.

6 Bibliography

/1/ Piechnick, M., Feuser, A. : MOSIHS - Programmsystem zur Simulation komplexer elektrohydraulischer Systeme
11. Aachener fluidtechnisches Kolloquium 03/1994

/2/ Piecknick, M. : Simulation mit Komfort - HYVOS 4.0 und MOSIHS 1.0
O+P Ölhydraulik und Pneumatik, 05/1994