A MOTION SEAT USING PNEUMATIC MEMBRAN ACTUATORS IN A HEXAPOD SYSTEM STRUCTUR

Michael Pohl
Bochum University of Applied Sciences, Mechatronic Center Northrhine-Westfalia
Lennershofstr. 140, D-44801 Bochum, Germany
Phone: +(49)234/32-10430, Fax: +(49)234/32-10472,E-mail: michael.pohl@fh-bochum.de

Abstract - The development process of a pneumatic powered motion seat is being outlined as an example for mechatronic design. The fluid muscle of Festo AG provides stick slip free motion and is being used as displacement and pressure controlled actuator in a hexapod system for the first time. The process of design is supported by 3D-CAD with the software tool SolidEdge. It provides the necessary data to use Rigid Body Simulation with the software tool CAMeLView. Actuator behaviour is acquired by using a test bench with similar environment to the designed application. An 80486 process controller system with modular periphery called PS-1 made by Beck-IPC is beeing used. The programming is done by defining the control structure in a block oriented simulation environment followed by automated C++ code generation and compilation for the DOS 6.22 operating system. The displacement control of the fluid muscle was possible due to the development of an incremental in-tube length measuring system. For this purpose the miniaturized magnetic linear encoder system had to be integrated into the membrane of the actuator. By using a six-actuator structure it is possible to move a person in the seat in three translatorical directions as well as three rotatorical orientations – all six degrees of freedom are available respective limited working ranges. By using the inverse transformation formalism for hexapod structures only forward position control of the motion seat is available. It is scheduled to implement the hexapod forward transformation to calculate the seat position and orientation in real-time in order to improve the control accuracy.

The motion simulator will be an example for an interesting application of fluid muscles launched by Festo AG. It is the intention to present the simulator at the next Hanover fair.

Keywords: pneumatic membrane actuator, hexapod structure, motion seat, mechatronic design, rigid body simulation, autocode generation

I. INTRODUCTION

1) Priliminary projects: At Bochum University of Applied Sciences in the last 10 years several motion simulators have been developed which are used to perform the movement of a person according to a simulated virtual environment. An early development was a roller coaster simulator with two pneumatic pistons and a cardan joint, which had a really bad dynamic behavior [Haas, 1997]. Quite similar in dynamics but with three pneumatic pistons was the MOTIONSEAT (Fig. 1) intended for virtual cave applications [Sikora, 1998].
Then followed the HANDLEX (Fig.2) with six electromechanical actuators arranged in hexapod structure beeing the first experiment with parallel kinematics in the laboratory [Stridde, 2000].

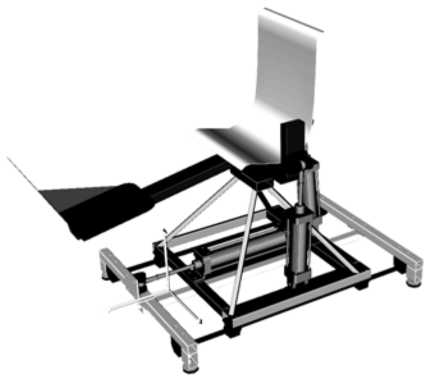

Fig. 1: MOTIONSEAT intended for virtual caves

All this motion simulators had disadvantages in dynamic behavior when using pneumatic pistons or in dimensions when using electro mechanic actuators. So industrial motion simulators usually are equipped with hydraulic actuators providing a wide dynamic range but unfortunately having the need of a costly hydraulic power supply. The advantages of the uncomplicated medium air are contrary to the disadvantages of bad controllability of the actuators; a fist formula says, that the provided pneumatic force should be more then three times of the weight that will be moved.

The recently launched fluidic muscle offers a solution from Festo AG, Esslingen, Germany (see 1.3). In 2004 Festo AG and Mechatronic Center Northrhine-Westfalia agreed to develop a simulation seat using fluidic muscles in hexapod structure.

Fig. 2: HANDLEX, industrial-handling applications

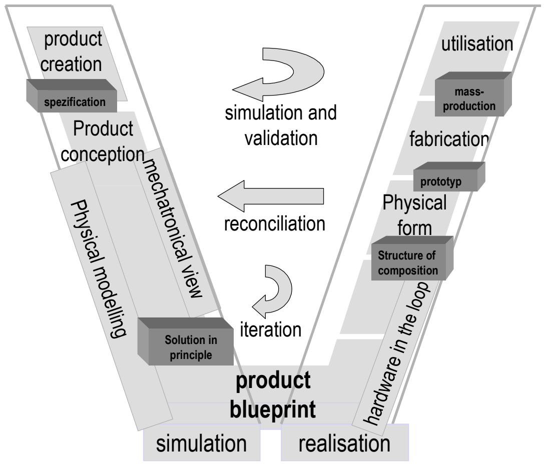

Fig. 3: The V - model, developing steps in mechatronic integration

2) *The development methodology of mechatronic systems:* In [Gau2001] the developing methodology of mechatronic products is favored on the subject of the V - model (Fig. 3). After product specification the design process is supported by virtual prototyping tools like computer aided design and multi body system simulation allowing multi domain flexibility between mechanics, software and electronics; by physical modeling the system dynamics are taken into consideration in the early virtual prototype phase.

3) *The development of the motion seat:* With the assistance of modern mechatronic tools the motion seat was developed und planned in an integrated draft process. The mechanical design was done completely in the 3-D-CAD system SolidEdge [Unigraphics]. By way of the general parametric mode of the designed CAD-model a variant construction was still feasible until simulation results would proof the successful dynamic behaviour. The MKS simulation was useful for several reasons: collision tests between seat and frame could be simulated in respect of very compact frame margins, multi body mechanics provide the simulation of forces and actuator behavior and nevertheless the control algorithms could be tested before the motion seat was build.

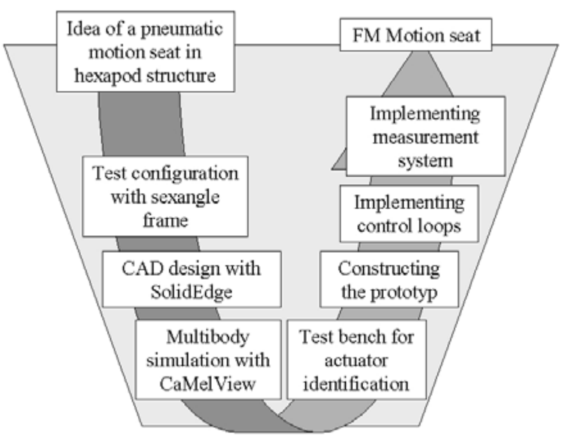

Fig. 4: Integrated development of the motion seat

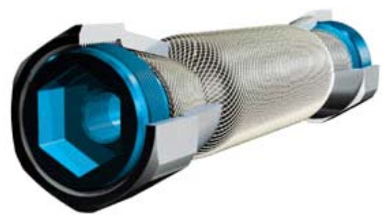

Fig. 5: sectional drawing of the fluid muscle

The software system CAMeL-View of iXtronics [iXtronics] was applied for integrated system simulation. Special preliminary examinations about the actuator behavior were simulated by means of WINFACT/BORIS [Kahlert, 2004].

4) CAMeL-View, a multi domain simulation tool: Mechatronic products have to be developed by means of virtual prototyping. One of the key problems in Computer-Aided Engineering is the multidomain modeling of the mechatronic system. To support the modeling, CAMeL-View provides a comfortable interactive way to build up models of complex mechatronic systems including different system domains, in this case study multibody, pneumatic and control engineering. The domain-specific model of multibody systems includes also the 3-D graphical description that can be imported from SolidEdge by using VRML interface and automatically reduced for animation purposes. For analysis, the domain-specific model can automatically be transferred to a mathematical representation [Meier-Noe, 2003].

5) The actuator fluidic muscle: The fluidic muscle is a membranous actuator with slight diameter compared to the possible force but with limited stroke up to 25% of length (Fig. 5). Compared to pneumatic pistons with the same diameter the fluid muscle provides 8 times the force. The optimal application is pulling heavy masses (Fig. 6) [Festo, 2004].
Festo AG provides a diagram of the static characteristics of the muscle with the three variables force, pressure and displacement (Fig. 7). Usually the displacement is expressed by the contraction of the muscle in relation to its initial length.

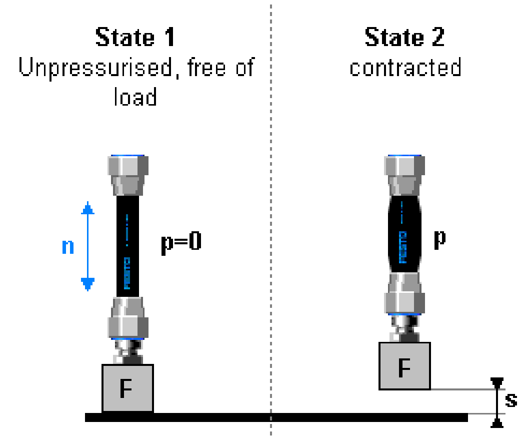

Fig. 6: fluidic muscle, two states of operation

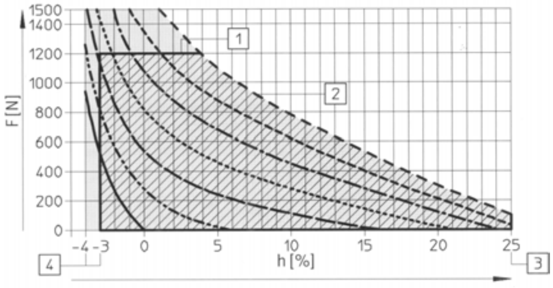

Fig. 7: Force characteristic of the fluid muscle MAS-20 vs. contraction h and pressures p from 0 bar to 6 bar maximum.

II. THE DEVELOPMENT OF THE MOTION SEAT

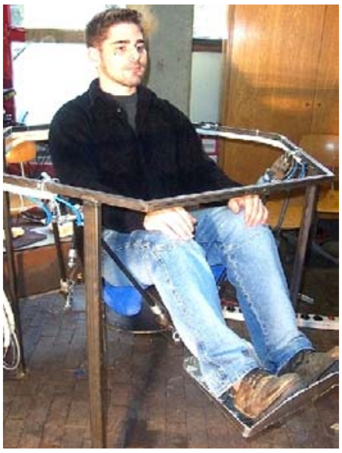

Fig. 8: Test configuration with sexangle frame

1) *Test configuration of the seat mounting:* In order to find the convenient configuration of the hexapod actuator structure a test frame was built up. CAD cannot substitute the real sensing of the seat mounting. Several modifications of attachment points and actuator angles related to each other where made and the best effect of the actuator movement on the effector was found [DeGiorgio, 2003]. In the chosen configuration the seat position feels rather inelastic when the pressure in the actuators remains constant.

2) *3D-construction of the chassis:* The dimension of the frame is adapted to the measures of the bucket seat, which CAD data was kindly provided by RECARO.

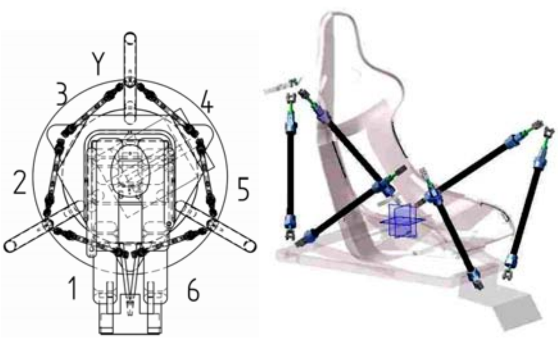

Fig. 9: Best actuator configuration in hexapod structure

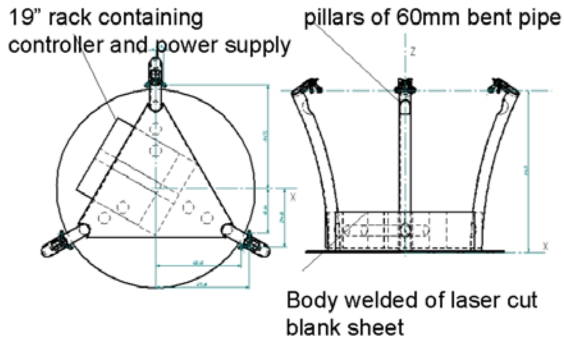

Fig. 10: CAD- Model of the frame

The main function of the frame is to hold the attachment points of the six muscles with little elasticity. Additionally the process controller and the pneumatic components have to be housed. According to this requirement three strong pillars are attached to a triangle chassis that is based on 3mm laser cut blank sheets (Fig. 10). The chassis contains a 19" rack drawer for the controller components and electrical wiring.

The suspended seat mounting is efficiently designed in a construction of 30mm rectangular tube beeing stiff but of light weight. To find a convenient position the bucket seat is tilted slightly backwards in its adapters and a support for the legs is beeing provided (Fig. 11).

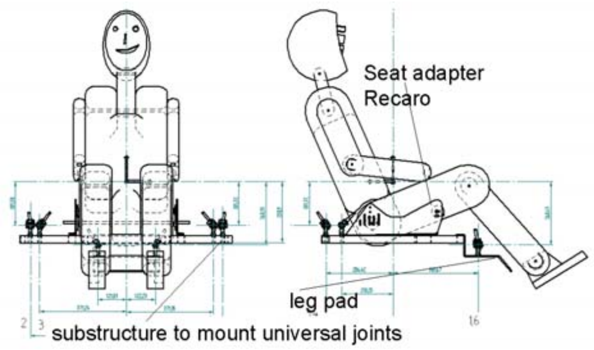

Fig. 11: CAD- Model of the seat mounting

The six fluidic muscles are attached to seat and frame by using fork heads and self-contained cardan joints on both endings, one end carrying the pressure supply adapter. Inside the muscle an axial guide bearing allows the adaptation of an incremental measurement system (Fig.12) [Sondermann, 2004].

3) *Multi body simulation with CamelView:* In order to carry out virtual collision tests and to simulate the movability regarding the limited stoke of the actuators a multi body simulation model of the entire motion seat was elaborated. The SolidEdge model could directly be used

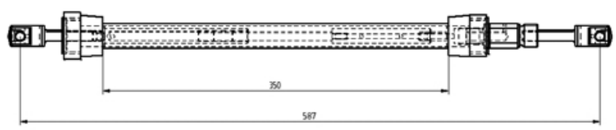

Fig. 12: CAD- Model of the actuator device

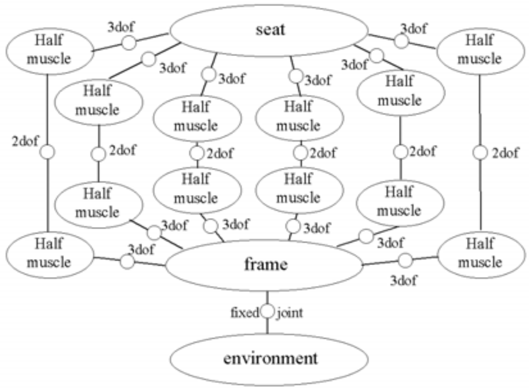

Fig. 13: model structure of rigid bodies and joints

regarding the VRML data and also the geometrical and physical parameters. Fig. 13 shows the structure of the connected rigid bodies with 48 DOF. The muscles had to be separated in two half muscles in order to express the axial joint for variable length.

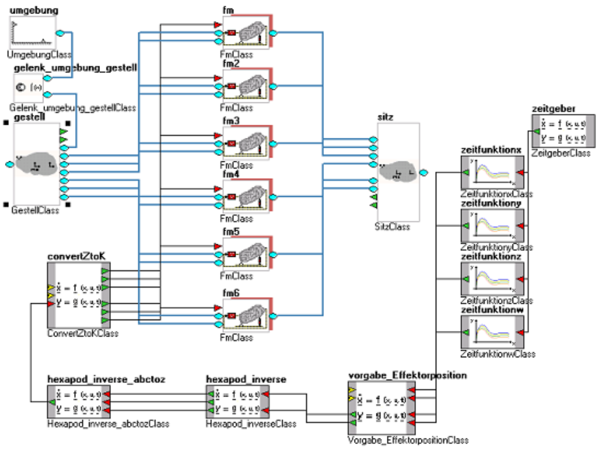

Fig.14: Complete CaMeLView model

The model was structured hierarchically in the environmental part "seat frame", in the dynamic parts "seat substructure" and the six actuators "fluid muscle system" and finally the modules generating stimulation signals (Fig. 14). Animation videos (Fig. 15) and timeplots (Fig. 16) are obtained as simulation results.

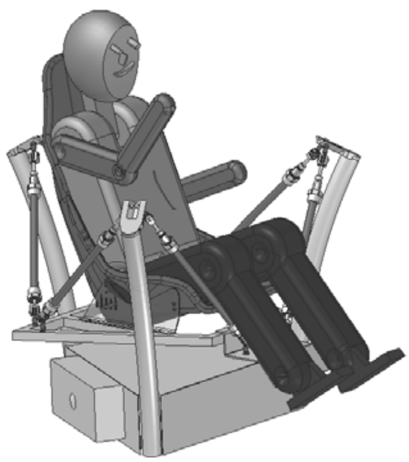

Fig. 15: Animated graphic of the rigid bodies

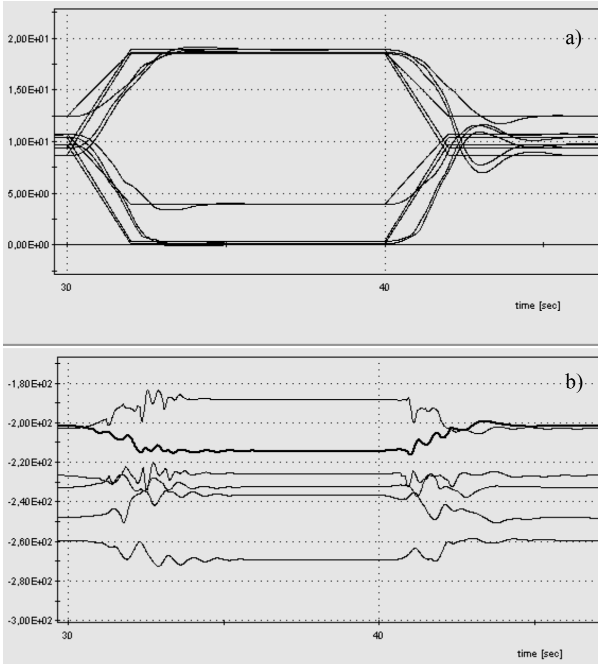

Fig. 16: Simulated results for six actuators rotating around z-axis a) contraction demand and controlled value in % b) Six forces in N

4) *Controller design for muscle contraction:* The test bench of the MAS-20 includes a joint bearing, a mass of 5 kg and sensors for measurement of displacement, pressure and force. For pressure control a valve type Festo MPPES-3-1/2 is used (Fig. 17).

With the test bench equipment frequency and step response measurement was carried out and the result in Fig. 18 were delivered.

Fig. 17: Test bench for fluidic muscle displacement.

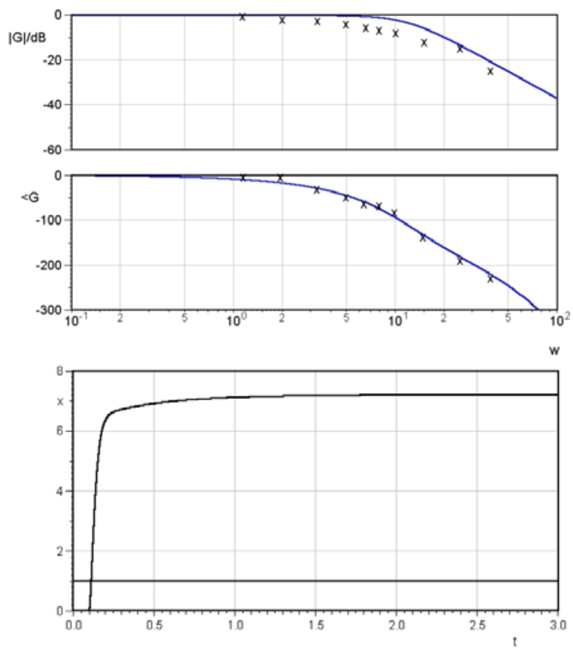

Fig. 18: Frequency response with model approximation and step response of approximated model

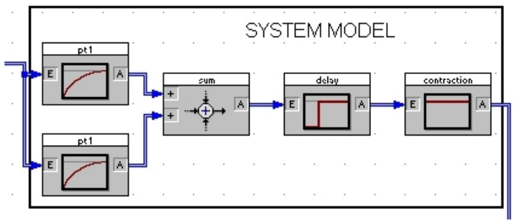

Fig. 19: Structure of the simulation model

The approximation of the transfer function of the fluid muscle system leads to the formula

$$G\ (S) = \frac{1+0.356S}{1+0.43S+0.012S^2} * e^{-0.1S} \tag{1}$$

and can be expressed by the structure in Fig. 19. The delay time and the creeping movement of the last 10% of muscle contraction are typical.

The controller design covers considerations for pole-setting and delay time compensation. Neglecting the delay behaviour a classical PIT1 controller

$$G_R(S) = 4.3\frac{1+0.43S}{0.43S*(1+0.356S)} \tag{2}$$

leads to PT1 behavior of the controlled loop with the following transfer function

$$G_{RK}(S) = \frac{1}{1+0.1S} \tag{3}$$

To take the delay time into account and avoid instability, the structure of the controller will be completed by a feedback signal that provides the lacking response of the controlled system during delay time (Fig. 20). The control loop has a performance of 0.2 sec delay and response time without overshoot.

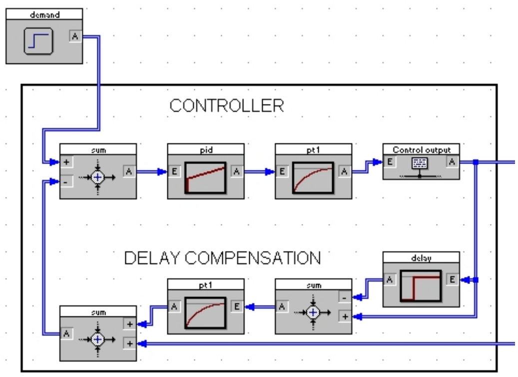

Fig. 20: Structure of the controller with delay compensation of the control failure signal.

5) Motion control of the hexapod structure: In order to control the movement of the seat in all six degrees of freedom the six muscle actuators have to be displacement-controlled according to the inverse hexapod formalism [Hahn, 2000]. The demand is given by the position of the seat. Using the algorithm the demand contractions of the six actuators can be calculated. At present a direct measurement of the actual muscle length is not available. It will be part of future development. Therefore in the first instance the muscle length will be estimated using the measured pressure and under assumption of constant forces. As the multi body simulation has offered the forces alter within 100N and so the contraction will be imprecise within 8% (see Fig.16) beeing sufficient for this application.

6) Micro controller hardware: To successfully calculate six control loops and the inverse hexapod formalism within 1ms sampling time in floating point formalism, the BECK PS-1 system with a 33Mhz 80486 CPU using DOS 6.22 was chosen. This modular micro controller system provides modules for analog signal in-/output and linear encoder interfaces, which will be necessary for the later installed measurement systems [Beck].

7) Autocode Generation: The program code was developed by means of automated Ansi-C-Code generation using the block oriented simulation language WINFACT/BORIS [Kahlert]. First of all the software had to be adapted to the operating system and the hardware interfaces of the PS-1 System. The inverse hexapod formalism was programmed in a DLL-module. An interface to use the SPACEMOUSE [3dConnexion] for motion demand and several interfaces for debugging were added. Because of the consequent top down programming method a very quick and easy development process was made (Fig. 21).

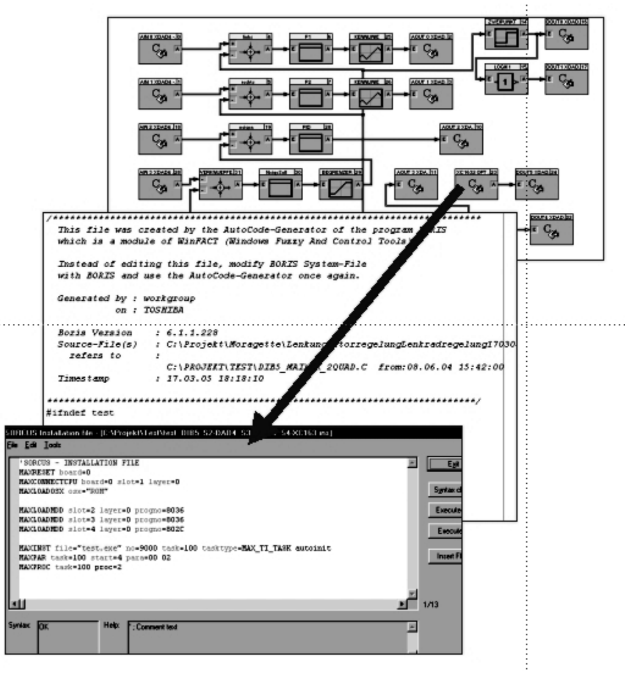

Fig. 21: Autocode generation with WINFACT

8) Manufacturing: The manufacturing of two frames of the motion seat took place in cooperation with the experienced tricycle producer Thorax GmbH, Germany

[Thorax]. The chassis is made of Laser cut blank sheets and the three pillows consist of bent pipes. The frame is a welded construction of high stiffness with several rips for strengthening. A robust and brilliant surface was achieved by powder coating (Fig. 22).

Fig. 22: The FM Motion Seat

III. CONCLUSION

The completion of the FM MOTION SEAT will be finalized. The experiences in using an integrated multi domain / multi body simulation tool together with 3D CAD in this special case are outstanding. Because of the complex design problems caused be hexapod structures and depending on the special actuator behavior a conventional development method would not have been successful.

IV. ACKNOWLEDGEMENTS

This work was supported by the Festo AG, Esslingen.

REFERENCES

[DeGiorgio, 2003] V. DeGiorgio, Konstruktion und experimentelle Inbetriebnahme eines Bewegungs-simulators auf Basis fluidischer Muskeln, diploma thesis SRT Laboratory, 2003.

[Festo, 2004] Info 501, Fluidic Muscle MAS, Festo Informationsschrift, 2004/03.

[Gausemeier, 2001] Gausemeier, J. and Lückel, Entwicklungsumgebungen Mechatronik. HNI-Verlagsschriftenreihe ISBN 3-931466-79-5, 2001

[Hahn, 2000] H.Hahn, W. Klier, D. Fürst, Mathematical modeling of spatial servo-pneumatic parallel robots, RTS Bericht 33, University of Kassel, 2000.

[Haas, 1997] S. Haas, Konstruktive Gestaltung und Projektleitung für einen zweiachsigen Bewegungs-automaten, diploma thesis, Fa.Tetron Ratingen 1997

[Kahlert, 2004] J. Kahlert, Simulation technischer Systeme, Eine beispielorientierte Einführung, Vieweg 2004.

[Meier-Noe, 2003] U. Meier-Noe, Modellierung mechatronischer Systeme - Basis der Systemauslegung und der Wissenskonservierung, VDI-Fortschritts-berichte Reihe 20 Nr. 279. 2003

[Sikora, 1998] K.Sikora, Entwicklung und Integration einer pneumatisch bewegten „Motion Platform" in eine „Cave for Automated Virtual Environment", GMD St.Augustin, 1998

[Sondermann, 2004] G. Sondermann, Fertigungs-gerechte Konstruktion eines pneumatischen Simulationssitzes mit Fluidmuskeln in Hexapod-anordnung, diploma thesis SRT Laboratory 2004

[Stridde, 2000] W.Stridde, Digitale Regelung eines elektrospindelgetriebenen Hexapode-Sitzes, diploma thesis SRT Laboratory, 2000

[Beck] www.beck-ipc.com, Beck IPC GmbH,Pohlheim-Garbenteich.

[Festo] www.festo.com, Festo AG, Esslingen Germany.

[iXtronics] www.ixtronics.de, iXtronics GmbH, Paderborn, Germany.

[Thorax] www.thorax.de, Thorax GmbH, Düren, Germany.

[Unigraphics] www.unigraphics.de , Unigraphics Solutions GmbH, Köln, Germany.

[3dConnexion] www.journeyed.com, 3dConnexion, Inc. Los Gatos, CA.

[Kahlert] www.kahlert.com Ingenieurbüro Dr. Kahlert, Hamm, Germany.