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THE RESEARCH OF VIBROISOLATION AT THE TECHNICAL UNIVERSITY IN LIBEREC

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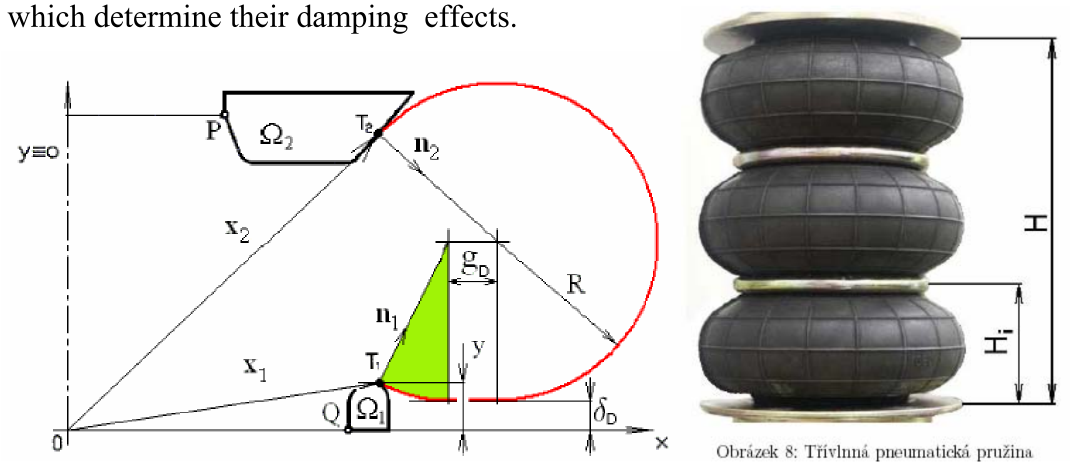
Summary: *The paper gives complete information both on theoretical and experimental research of vibroisolation problems at the Technical University in Liberec and on innovation at expansion of its laboratory.*

1. Vibroisolation elements

A. Pneumatic springs

Many vibro-isolation elements are made of elastomers, especially of carbon black-filled rubber and of rubber matrix composites. The successful modelling of their behaviour needs constitutive models which represent the dynamic properties of rubber under infinitesimal and inite thermomechanical deformations. One part of the research in our laboratory is the intensive experimental and theoretical investigation of these materials. The development of models for elastic behaviour of orthotropic composites with rubber matrix reinforced by cords and the experimental determination of their parameters were the basis for successful FEM simulation of deformation of an air-spring [1],[2]. Nowadays we concentrate on the non-elastic behaviour of these materials, especially on their visco-elastic properties which determine their damping effects.



Pic. 1 Three-wave pneumatic spring and its section.

At the partial problem "The model and experimntal optimization of pneumatic suspension elements" there are studied proprieties of bellows from laminated rubber with cord reinforcement of the effect, their forming and application of load (axially and extra-axially) on the basis of the model and experimental analysis of geometrical and load characteristics of the air springs, experimental verification of a dependence of characteristics during dynamic loading in various configurations (Pic. 1).

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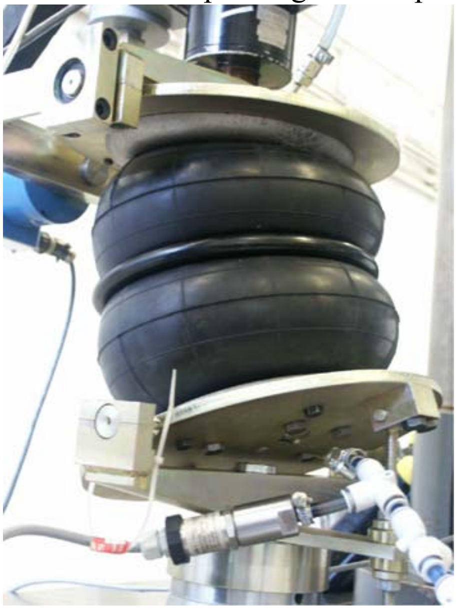
In the first phase, a theoretical research was concentrated on an observation of geometrical characteristics of air-operated bellows springs, especially on a shape of the meridian of the bellows wall depending on the spring axial deformation.



Pic. 2 Two-wave pneumatic spring, generally loaded.

The designed method is suitable, especially when projecting new bellows air-operated springs as well as other spring types for which analogous conditions can be accepted. It concerns diaphragm and combined springs (combination od diaphragm or bellows springs with bag springs having external bandage where profiles of bearing surfaces and bandages can be more complex).

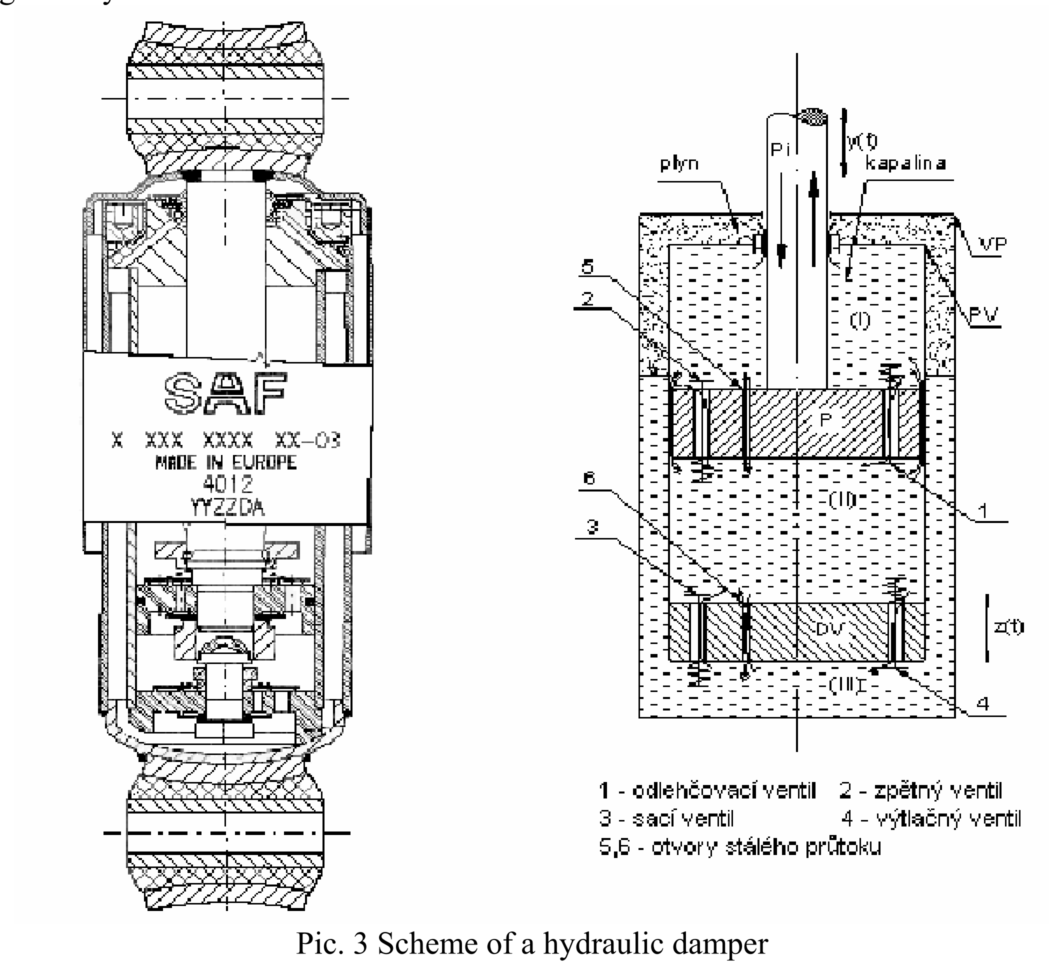
B. Hydraulic dampers

The teoretical research of the hydraulic damper is focused :

1.at the description of two-phase fluid with steady mass of free and dissolved air ;

2. at the description of steam or gas cavern;

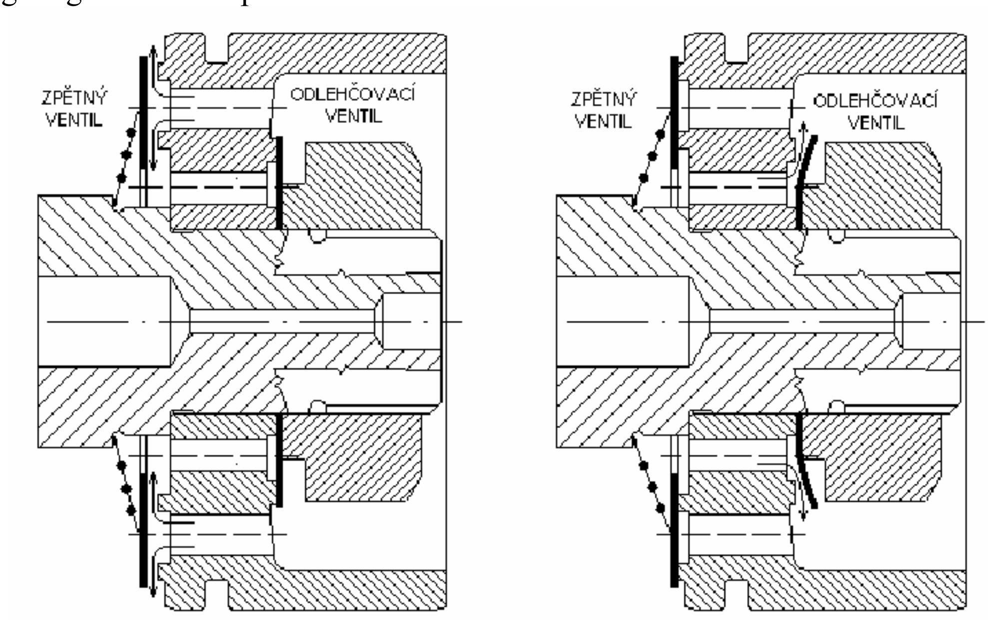
3. at the limitation of the area of the self-excited vibrations of the valve-system which are closely connected with acoustic shows of the damper.



Pic. 3 Scheme of a hydraulic damper

In the field of hydraulic damper modeling further research was focused at the specifications of description of mechanical damper components and specification of flow conditions inside the damper.

To set the non-linear valve stiffness a special identification method was developed, which comes out from experimental data and in combination with results of numerical simulations provides relatively precise description of the valve stiffness in the whole operating range of the damper.

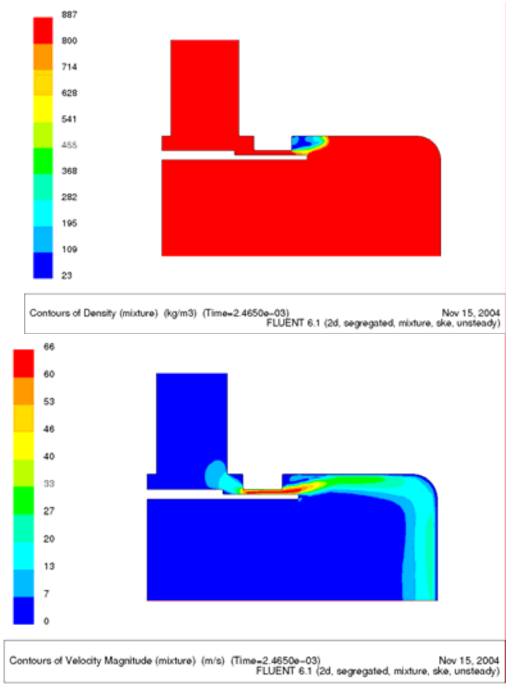


Pic. 4 Location of the check and relief valves on the damper piston.

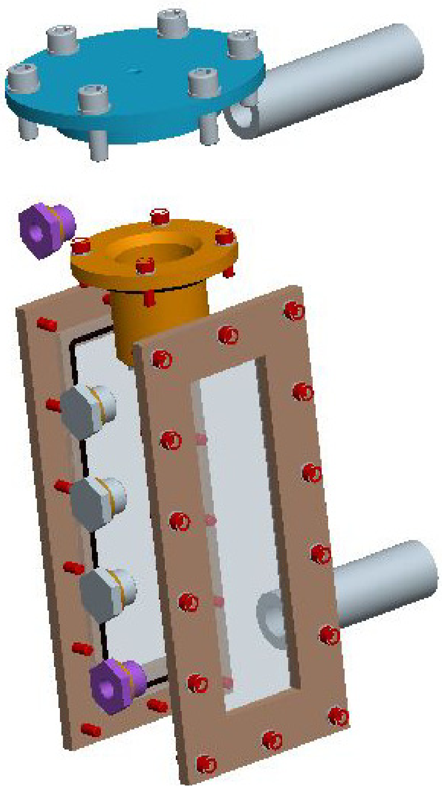
To improve description of flows through valves a new, corrected formula for discharge flow coefficients based on the measurements of flow characteristics of trottle elements of the damper with constant as well as variable slot width was implemented into the model.

To come near the real dampers working with an oil containing free and dissolved air a more precise model of hydraulic damper supporting evolution of both air and oil vapor caves in working areas was derived.

The aim of the research is the determination of the origin of the cavity. The results of the numerical calculation served to the suggestion of the experimental model of the measuring chamber (Pic. 5). It is proposed to follow the origin of the cavity and the influence of the trottling slot on the course of the flow in the damper. The numerical simulation of the origin and the response of the cavity in the hydraulic damper (Pic. 6) with help of the commercial CFD software FLUENT, in which there was formed 2D and 3D model for the proposed geometry of the measuring chambre. The 2d model was completed with the interaction of the fluid and the trottling planchet.



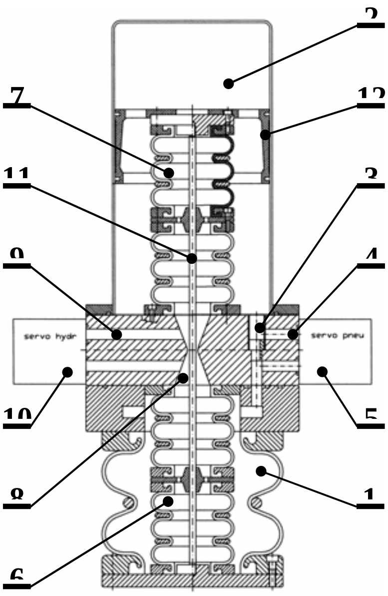
Pic. 6 The numerical simulation of the cavity response in the damper.



Pic. 5 Experimental model of the cavity chamber.

C. Hydropneumatic member

The development of hydro-pneumatic rubber-bellows suspension has been performed at the TU Liberec during last three years. The element shown in Fig. 1 is intended to be used for suspension of truck's back axle. The suspension unit consists of hydraulic and pneumatic parts, see Fig. 1. The silicon oil is used in the hydraulic part. The spring and damping characteristics could be changed in the case of a semi-active or active control. The development of the described hydro-pneumatic suspension unit has not been finished yet.

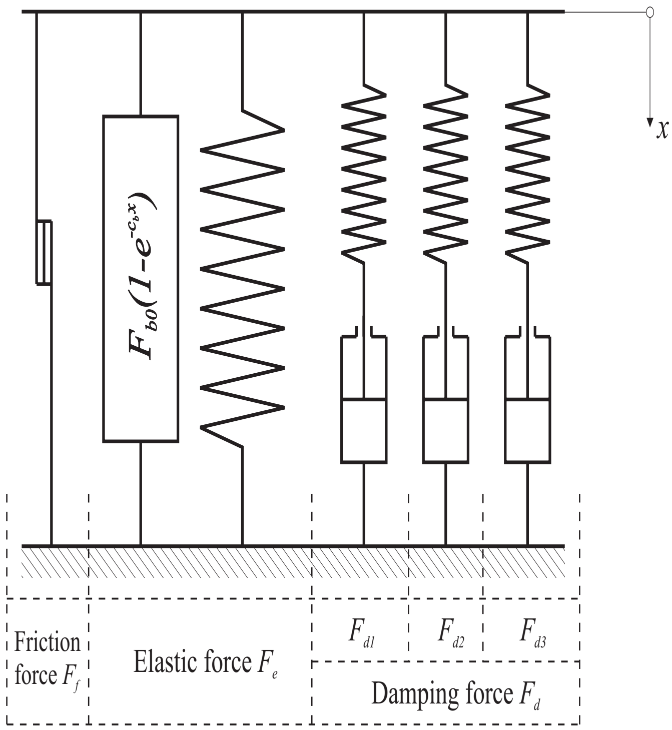


Pic. 7 Scheme of the hydro-pneumatic menber.

D. Polyurethane foams.

The elastic properties of the foam respect the first initial degressive loading section during compression and the following progressive course with vertical asymptote. The viscoelastic behaviour is described by the Maxwel members and the friction is also respected. This model has been verified with satisfaction.

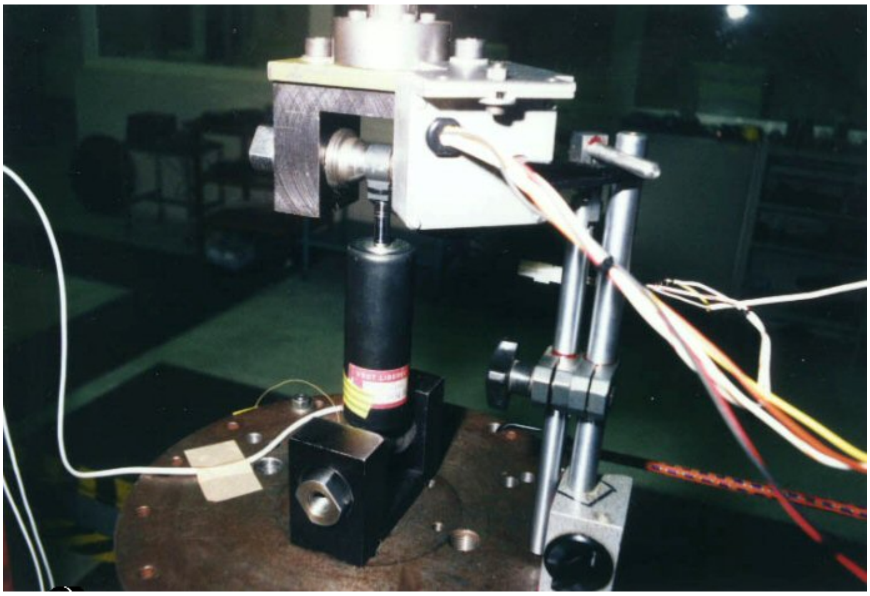
Pic.8 Vacuum chamber



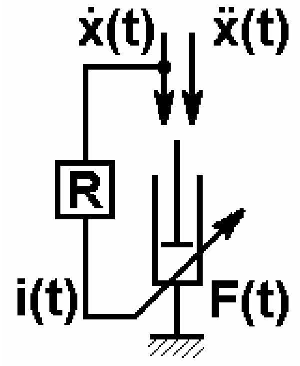
Pic.9 Rheologic model of the polyurethane foam

Polyurethane (PU) foam is predominantly used in driver seat production. For computer simulated statical or dynamical comfort of seating it is necessary to describe its properties in sufficient degree which this work deals with. Except some properties known before there was identified linear course of damping force dissipated work on frequency of harmonic kinematic excitation, and independency of damping force extreme on the same parameter. Measurement done in vacuum chamber (Pic.8) indicates that contribution of owing air through opened cells polyurethane is negligible with regard to material dumping. The method of damping force approximation in analytical form was developed. Furthermore rheologic model (Pic.9) of polyurethane foam has been drawn up and verified by harmonic and triangle kinematic excitation. Although the complete car seat is far more complicated system its behavior shows qualitatively the same properties as the specimen of PU foam.

E. Magneto-rheological damper is a kind of controlled damper. Its characteristic can be changed by the modification of properties of the working liquid using controlled magnetic field. To full analysis of magneto-rheological damper it is necessary to identify damping force as function of velocity and actuating current of magnetic field. Its simulation model was used to design the control system with PID controller (see [5]). We solve the application of the magneto-rheological damper for a car seat absorption system and an active damping system of the ambulance coach.



Pic. 10 Control of the magneto-rheological damper

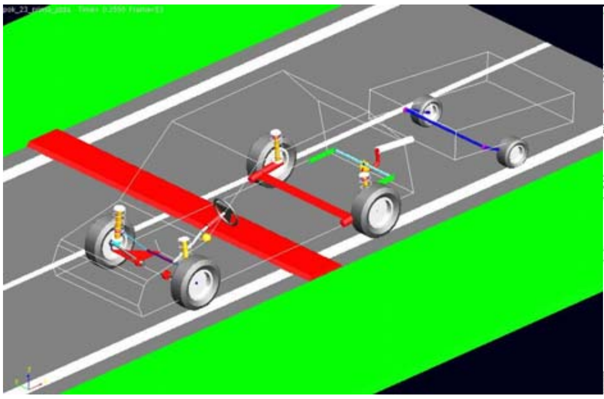


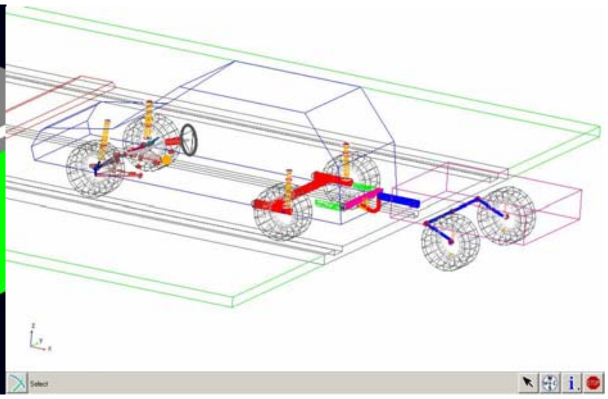
Pic.11 Scheme of the control

2. Vibroisolation systems

A. Model of towing bracket of passenger car.

The aim of our research is to improve the towing bracket of the passenger car (Pic. 12) with respect to minimalisation of the dynamic effects transferred from the trailer to the vehicle body when crossing various terrain obstacles or various maneuvers. A three-dimensional model of a car with flexible trailer was created in the software ADAMS/Car (Pic.13). The model is numerically very unstable, which adverts to problems while similar cases are simulated. Thanks to this fact, we are tuning the model to give better, stable solutions. The computed results are validated in two ways. Firstly we compared the results with those done in a simpler two-dimensional model created in the Working Model 2D software. Secondly we compared the results with the measurement that was realized in a real vehicle with a trailer.

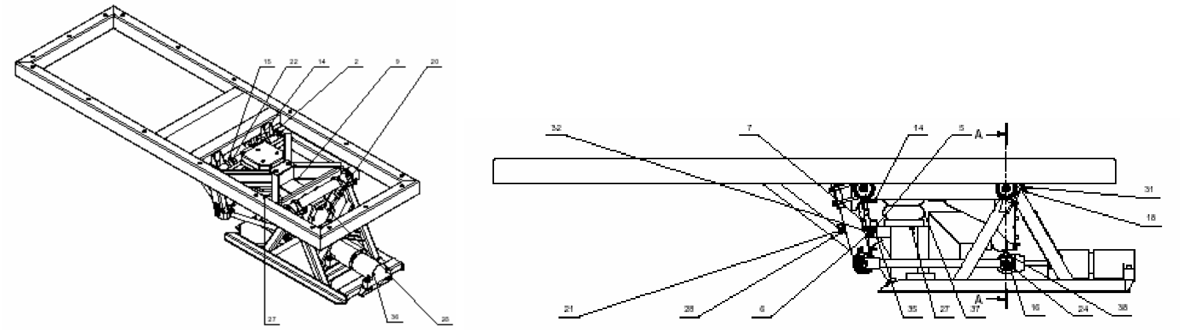




Pic.12, Pic.13 Towing bracket of the passenger car

B. The vibroisolation system of the ambulance couch with one degree of freedom

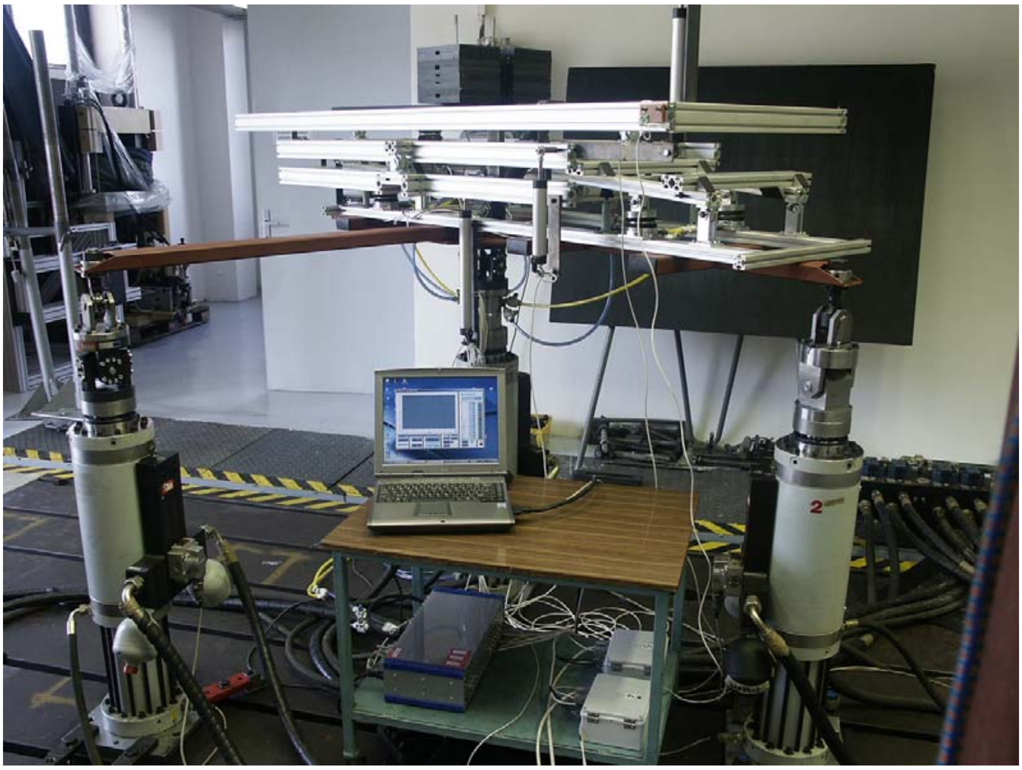
This system was brought to the stage of the prototype. The production documentation was submitted to the production plant CIEB (Pic. 14). The pneumatic spring is provided with an additional volume. In order to improve the personal feelings of the patient, the couch is inclined to the plane perpendicular to the apparent vertical and it has got adjustable bearing surfaces. At the present time a marketing survey is being done at individual first-aid stations.



Pic.14 Scheme of a spring loaded ambulance couch with 1° of freedom.

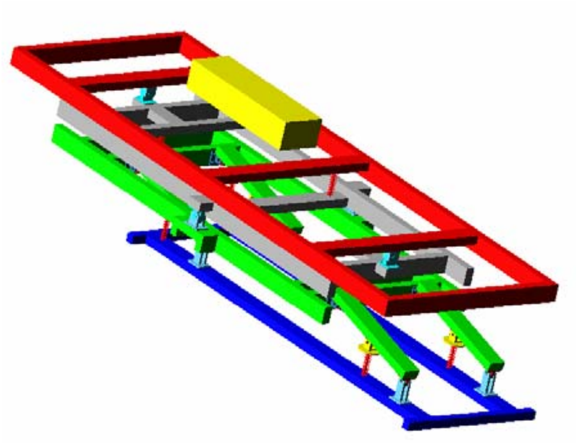
<u>C. The vibrisolation system of the ambulance couch with three degrees of freedom</u>

This system is solved in two levels: continuous model of human body (crash model from Mecas) and discrete model(from ALASKA - load described with mass, position of mass centre and central inertia tensor(Pic. 16)). The testing of the accordance of the both models led to the forming of a hybrid model. At this time, there is being solved the response of the kinematic excitation in one or two directions (Pic. 15). The system has both external and parametric excitations and also a possibility of tuning into the internal resonance.

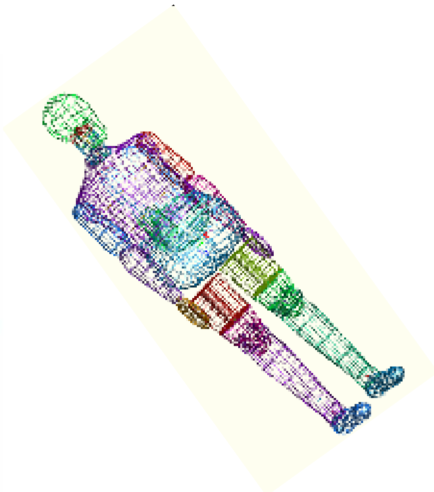


Pic.15 Testing stand for the ambulance couch.

The complete system can be modeled by MKP:The calculations were made with PAM-CRASH 2g software, for which there exists a range of various models of human body. A dummy figure (Pic. 17) with a model of abdominal cavity was put into a lying position. It is possible to analyse the responses of the human body to the ecitation. Simultaneously with mathematical calculations there was nade an experimental research.



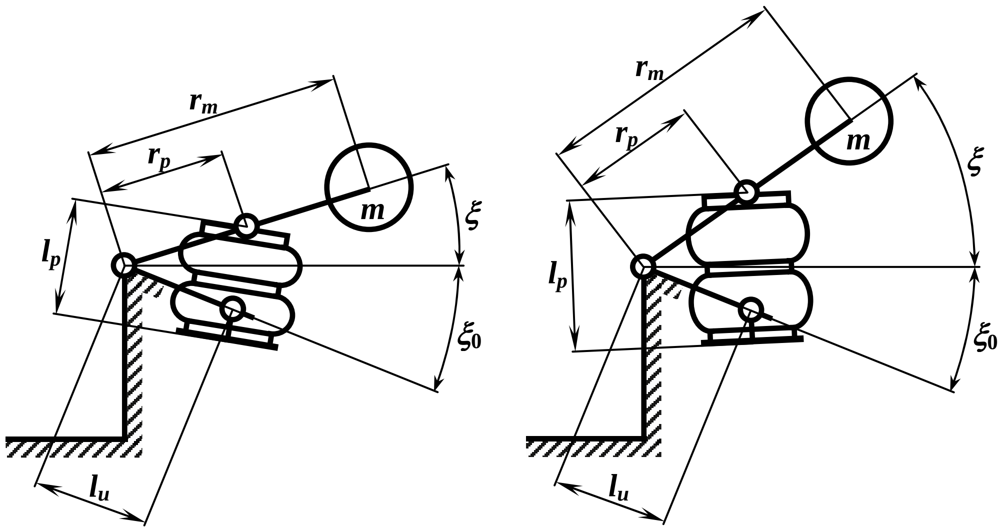
Pic. 16 Ambulance couch with the concentrated load.



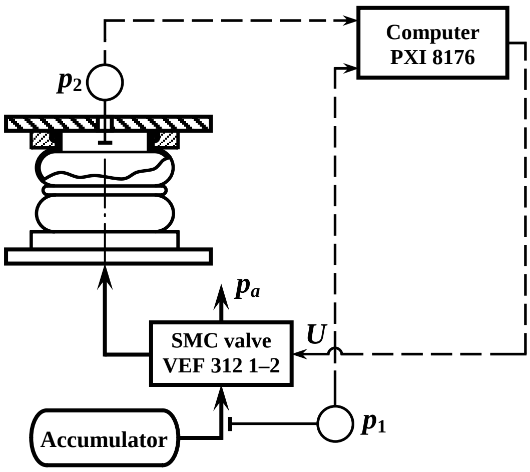
Pic.17 Dummy figure.

D. Development of active vibration suppression of driver's seat

A laboratory model - the part of parallelogram mechanism with the ball bearings in the joints has been constructed. Various feedback control algorithms have been developed. The PXI 8176 - National Instruments computer (LabVIEW) is used for measurement and control of the laboratory model (Pic.18 and 19). All of the control algorithms include compensation – linearization of the strongly non-linear flow characteristics of the pneumatic valve. An on-line optimization algorithm of coefficients of feedback control algorithms is currently being developed and tested. A redesign of the laboratory model aiming at decreasing the undesirable friction effects is being done concurrently.



Pic.18 Scheme of the substituted model of the driver seat.

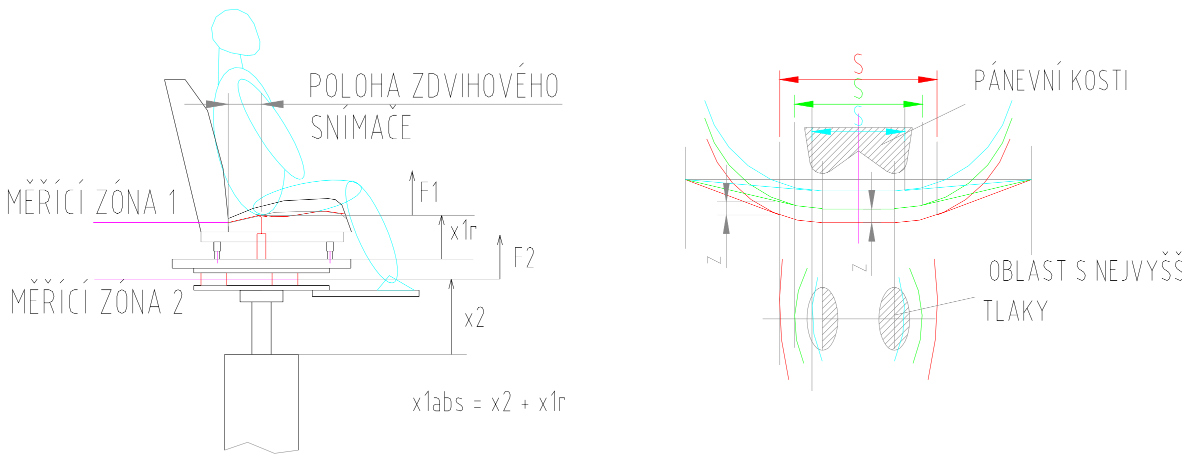


Pic.19 Scheme of the active control of the seat spring.

3. Biomechanics

The evaluation of the vibration loading of the biomechanical system of the sitting person and its interaction with the mechanical system of the seat is accompanied with simplified presumptions. These circumstances are demonstrated and the other signicificant influences-until now neglected-are stated with regard to the properties of the population sample (Pic. 20).

The interaction of the biomechanical system and the seat is more or less individual. The study suggests that the current kinematic criteria of the evalution are completed with energetic criteria(criterion of the density of the energetic flow, criterion of the resultant dissipated energy, etc.).



Pic.20 Biomechanical system of the sitting person.

4. Means of experimental research

The equipment of the laboratory is continuously innovated and completed:

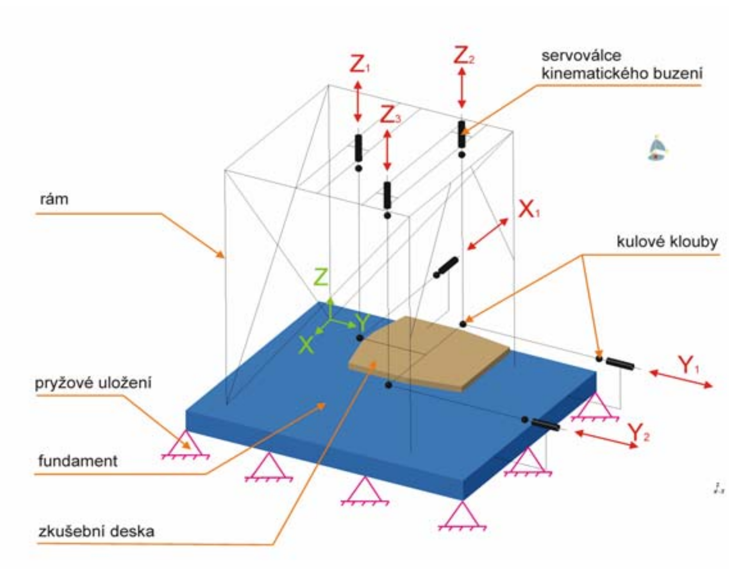
<u>A. The vibration platform with six degrees of freedom</u>

This platform has been finished and currently its testing is being done. It will play a basic role in such an investigation where accelerations in three directions as well as three angular acceleration components measured in a real vehicle should be reproduced in the test facility (Pic.21).

The process of transmission of measured data to the test bed has two principal steps both solved using principles of matrix 3D kinematics.

In the first step, platform motion corresponding to the given measured data must be expressed in terms of local platform reference point position vector components and three spherical angles. There must be additional conditions applied to the process to keep the motion periodic.

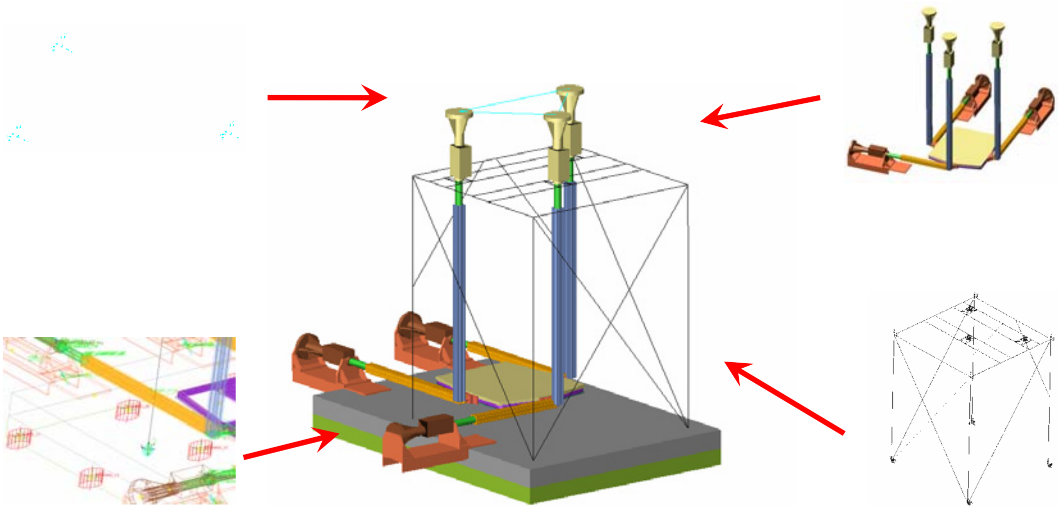
In the second step, from the resulting periodic motion of the platform must be computed motions of the test facility driving linear hydraulic motors, accepting their limited strokes.



Pic. 21 Vibroisolation platform with 6° of freedom

Pic. 22 Scheme of the platform

A natural conclusion is that not every given experimental data are reproducible in the test bed. So, measured data should be filtered in advance from this point of view, using the developed program.

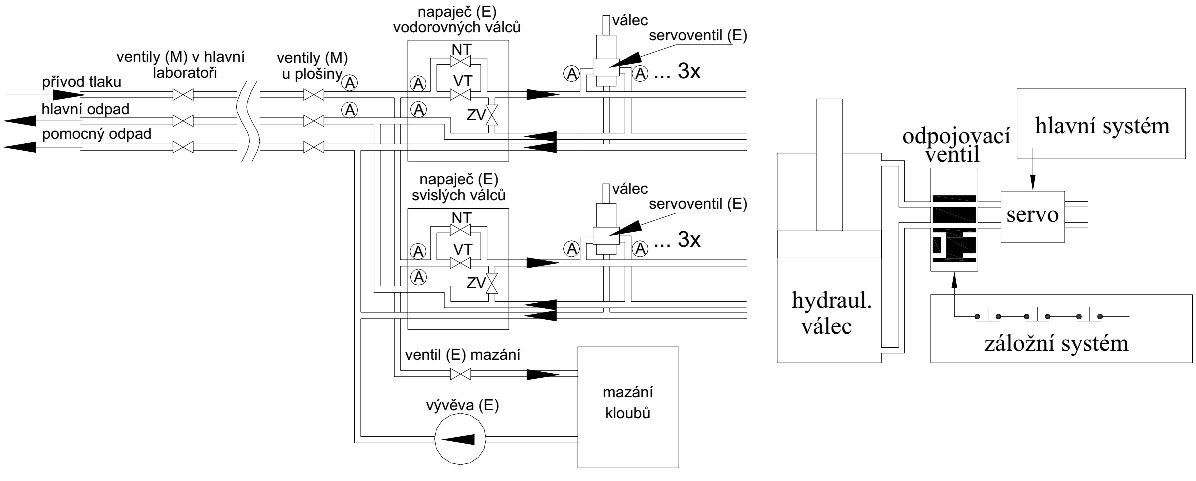


Pic.23 Virtual model of the platform

Simultaneously there is being done research work on the dynamic model of the platform (Pic.21 and 23):

1. Calculation of natural frequencies.
   The model is made in the ANSYS environment. For the forming of the model there were used in total five different types of elements and five different material models. There appears a necessity to solve the problems of the compatibility of the elements – d.g. SOLID 45 and BEAM 4. The model contains 5429 elements and 19254 degrees of freedom. The calculation of natural frequencies is provided by Block-Lanczos method in interval (0-1000Hz).
2. Conversion of FEM model and its condensation for MBS.
   From the analysis of the natural frequencies it is obvious that the properties of the frame of the trial platform and the stiffness of the location of the whole machinery have a substantial influence on the behaviour of the whole construction. In order to reach the conversion from FEM into the MBS, the model is devided and only the frame itself and the reinforcements of the location of the electrohydraulic servocylinders are connected. The models are condensed by Craig- Bampton method. The rest of the model is made with the imported geometry of the CAD system and has the properties of the rigid bodies. The first natural frequencies were calculated and the agreement with the original FEM model was reviewed.

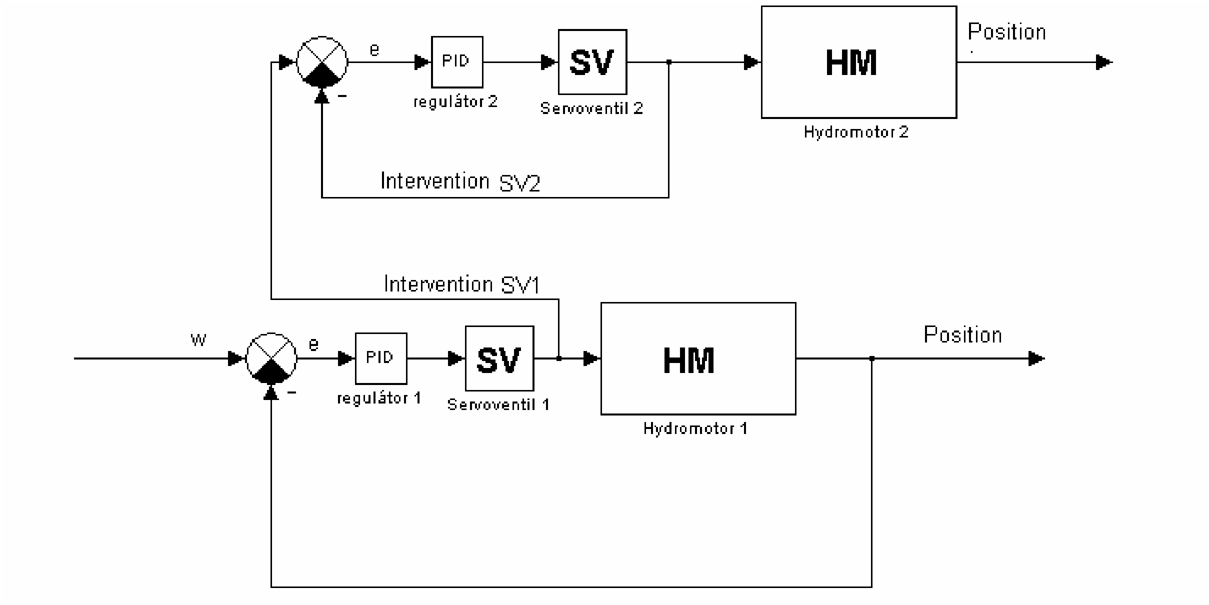
3) The control system for six degrees of freedom platform consists of two independent subsystems (Pic. 24). The main subsystem provides control of all power-actuating elements of the platform. Software-based PID controller generates required values for servovalve of each of the six hydraulic pistons. The subsystem works using a special real-time operating system running on a National Instruments industrial computer PXI 1002. The second system serves as an emergency backup that ensures safe platform stop in case of a critical situation. It is based on a simple relay unit. The system observes TOTAL STOP buttons, evaluates if position limits for every piston are not exceeded and checks proper control subsystem function by a watchdog. The emergency subsystem has serial interconnection, thus new safety circuits can be added easily. In case of an emergency situation the power fluid input is cut-off by a special valve, thus the platform movement is stopped regardless status of other system components.



Pic.24 Control system of the platform.

B. Doubled stand - tandem of two servocylinders

For the reason of the experimental research of the hydraulic dampers the original stand was doubled. That was necessary for reaching high intensity volume flow of the working liquid through the measured trottling elements.



Pic.25 Doubled stand-tandem of two servocylinders.

5. Acknowledgment

The research has been supported by MSMT n. 4674788501 “ Optimalizace vlastností strojů v interakci s pracovními procesy a člověkem”.

6. Literature

[1] Tran Huu Nam,(2004) Mechanical properties of the composite material with elastomeric matrix reinforced by textile cord, *Doctor dissertation work.* TU in Liberec

[2] Urban, R.,(2004) Simulation of engineering elements from rubber reinforced by threads, *Doctor dissertation work (in Czech)*, TU in Liberec

[3] Matějec, R. (2005) An Experimental Research of Flow Characteristics and Discharge Coefficients of Throttle Elements in Hydraulic Damper. *Doctor dissertation work (in Czech).* TU in Liberec

[4] Cirkl, D. (2005) Mechanical properties of polyurethane foam. *Doctor dissertation work (in Czech).* TU in Liberec

[5] Votrubec, R. (2005) The Global characteristics of the hydraulic dampers *Doctor dissertation work (in Czech).* TU in Liberec