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ACTIVELY CONTROLLED AIR-SUSPENDED DRIVER’S SEAT – FROM LABORATORY TO TATRA PROVING GROUND

AKTIVNĚ ŘÍZENÉ VZDUCHOVĚ ODPRUŽENÉ SEDADLO ŘIDIČE – OD LABORATOŘE K POLYGONU TATRA

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Anotace: Při jízdě po nerovných vozovkách nebo polním a lesním terénem v mnoha případech již pro účinnou ochranu řidiče před působením zdraví škodlivých vibrací nestačí pouhé pasivní odpružení podvozku vozidla a sedadla řidiče. Výrazného snížení vibrací 6působících na řidiče bylo dosaženo pomocí nově vyvinutého aktivního zpětnovazebního řidicího systému sedadla řidiče. V článku jsou diskutovány přenosové vlastnosti běžného pasivně odpruženého sedadla a vyvíjeného aktivně odpruženého sedadla, dosažené na počátku jeho vývoje. Ve stručnosti je popsán řídicí systém aktivního sedadla. Uvedeny jsou výsledky laboratorních testů zvoleného pasivního a vyvinutého aktivně odpruženého sedadla s figurínou se dvěma stupni volnosti. Výsledky jízdních testů obou koncepcí odpružených sedadel s řidičem ukazují na aktivní spolupůsobení řidiče, nezávisle na typu odpruženého sedadla.

Klíčová slova: Sedadlo řidiče, aktivní vibroizolační systém, pneumatická pružina, jízdní zkoušky

Summary: For the human health protection against vibrations in cases off-road drive and drive on rough roads is known, that the only passive vibration isolation of car suspension and driver’s seat is not sufficient. Significant decreasing of vibrations acting on driver was achieved with design and realization of feedback control of driver’s seat. Transmissibility characteristics of passively suspended seats are discussed. Transmissibility of the developed actively suspended seat, demanded at the start of the development, is shown. Control hardware and software of the seat are briefly described. Laboratory testing procedures with 2-DOF dummy and their results on passively and developed actively suspended seats are shown. On-road measurements of suspended seats with driver on a truck were carried out. Results showed active involvement of the person, sitting on any suspended seat, on the control of his motion.

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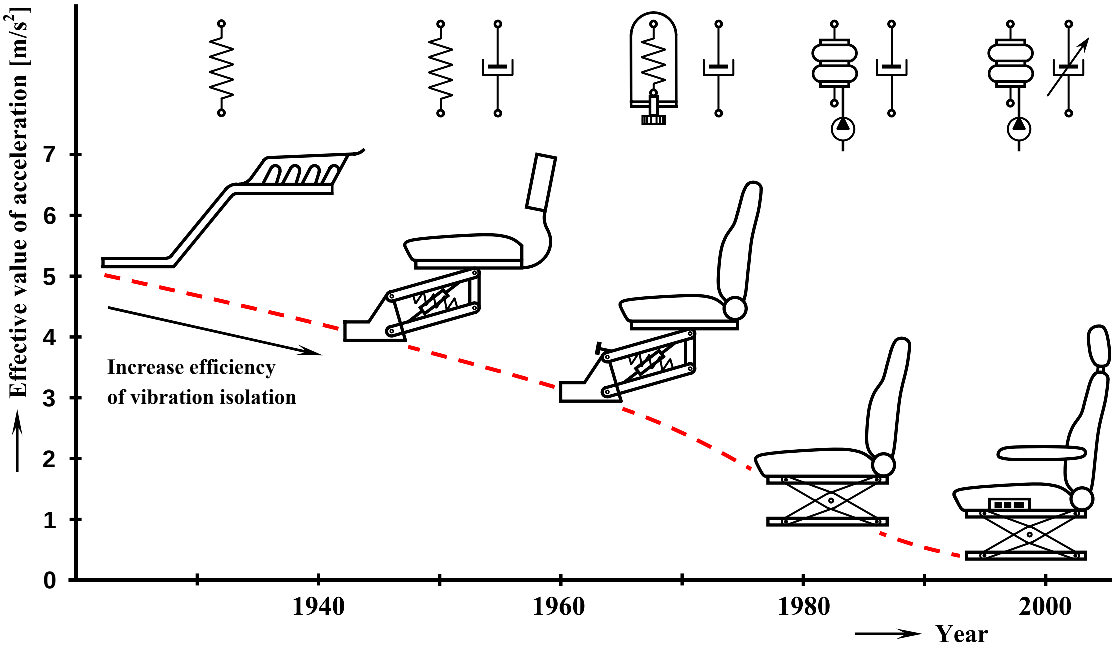
Key words: Driver seat, active vibration isolation, pneumatic spring, driving tests

1. INTRODUCTION

The band of highest human sensitivity to vertical vibrations is between 4 and 8 Hz. From the view of good vehicle handling is also very important the band of frequencies under 4 Hz.

The common passive vibration isolation systems of most frequently consist from springs and hydraulic dampers (see history overview, fig. 1). Some of them are seats with possibility of damping adjustment. The important parameter of these systems is natural resonance frequency f_n (resp. $\omega_n = 2\pi f_n$) of undamped system. This frequency is defined with spring stiffness and weighting mass. In case of damping coefficient increasing is decreased the vibrations transmissibility for lowest frequencies than f_n, on the contrary vibrations transmissibility for highest frequencies than f_n is increased. Choice of spring stiffness and damping coefficient is in all passive vibration isolation systems a compromise between these contradictory demands. The controlled dampers are used in semi-active vibration isolation systems. With the use of these systems in construction of drivers seat was not achieved significant improving of vibrations transmissibility in comparing with passive systems.



Source: lit. [1] and [2]

Fig. 1 – History of development of suspended driver's seats

Main contribution of active system is decreasing of vibrations transmissibility for low frequencies and also remaining the low transmissibility for high frequencies. In designed system is not used damper. Contrary of the commonly described systems in the designed system is used the electronically controlled servo-valve, which feeds the air into the spring, or discharges the air from the spring into the atmosphere.

2. PASSIVE AND ACTIVELY CONTROLLED AIR-SUSPENDED SEATS

2.1 Transmissibility of the passively air-suspended seats

Most trucks and buses are equipped with suspended seat for the driver (see fig. 2). Most seats in production are air suspended passive seats with possibility of damping adjustment.

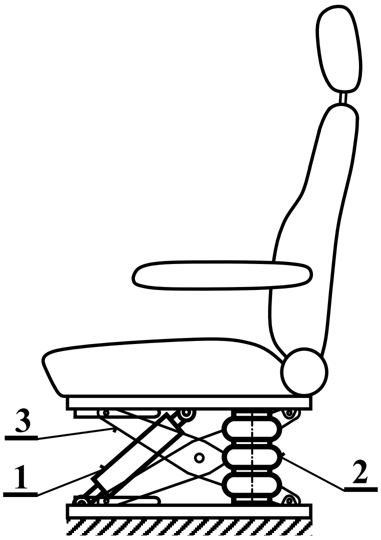


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Fig. 2 – One common arrangement of modern air suspended seats
(1 – scissors mechanism, 2 – air spring, 3 – hydraulic damper)

These passively suspended seats can be considered as 1-DOF dynamic systems with transmissibilities following closely basic theory of 1-DOF linear system. Amplitude and phase transmissibilities (movements of mass z_2 to base movements z_1) of such system are commonly known, see figs. 3 and 4.

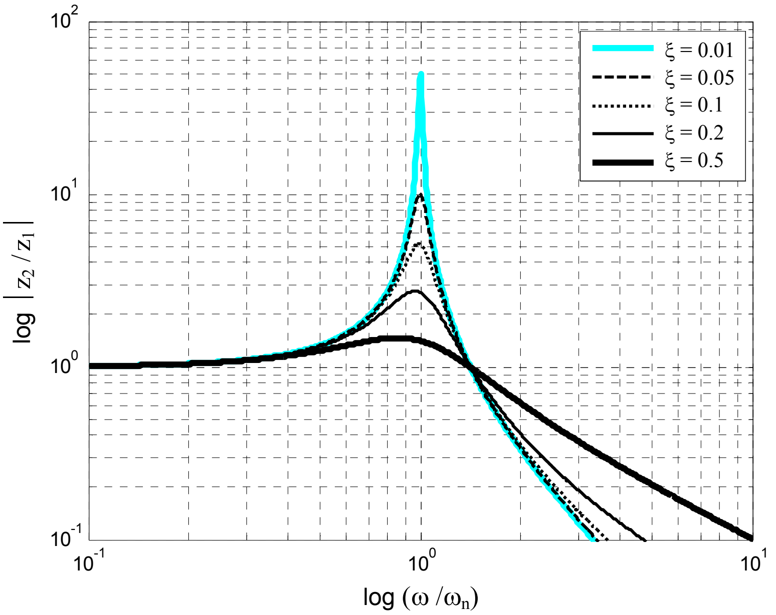

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Fig. 2 – Amplitude transmissibility of linear kinematically excited 1-DOF dynamic system

Suppression of resonance effects needs relatively high damping ratio (signed as ξ), but this leads to higher transmission of base movements with over resonant frequencies, and vice versa.

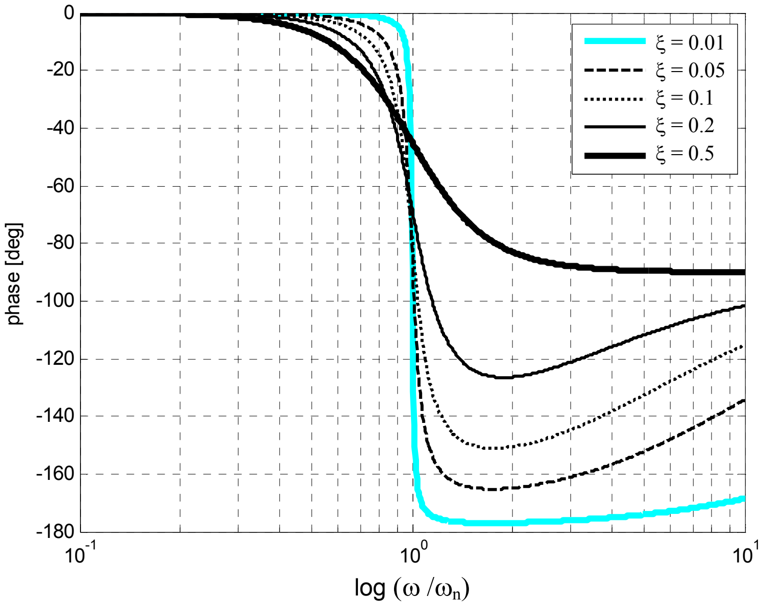

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Fig. 3 – Phase transmissibility of linear kinematically excited 1-DOF dynamic system

Actual transmissibility of real passively suspended seats are very similar to the simple theoretical one shown, as was confirmed by laboratory measurements (figs. 4 and 5), even when using a 2-DOF dummy (fig. 6). In this case the passive seat was excited by a quasi-stochastic signal (signed as Tatra) gained on the road by measurements with “low damping” and “high damping” settings.

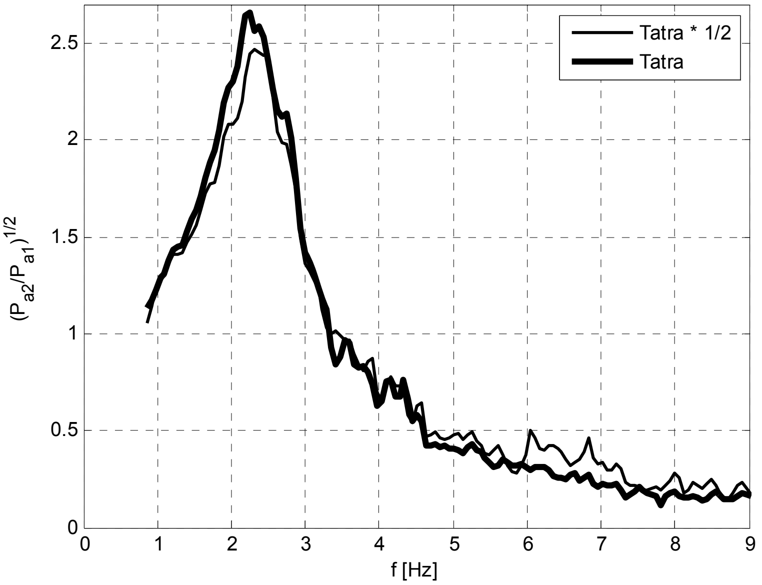

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Fig. 4 – Example of amplitude transmissibility of one real passive seat with “low damping” settings

P_{a1} is the power spectral density (PSD) of the seat base acceleration a_1 and P_{a2} is the PSD of the seat cushion acceleration a_2.

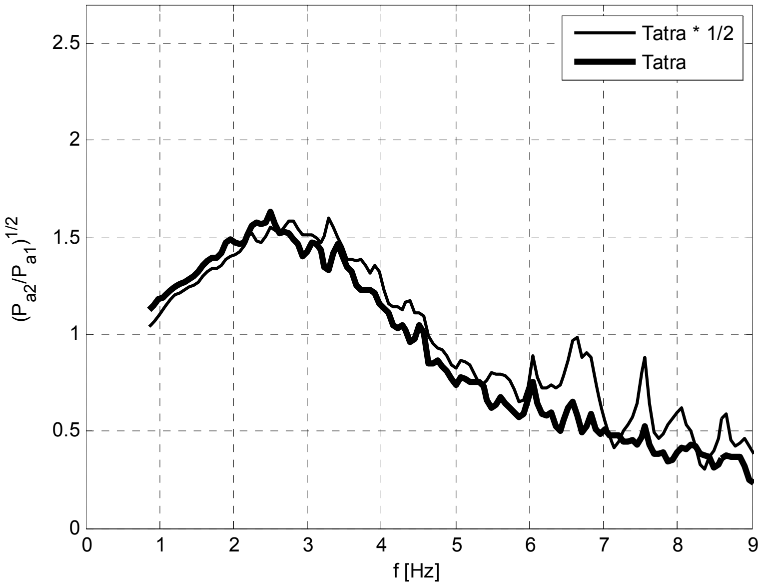

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Fig. 5 – Example of amplitude transmissibility of one real passive seat with “high damping” settings

It must be emphasised, that transmisibility of passive seats is practically very little affected by the type of the input signal.

Source: Authors

Fig. 6 – Laboratory testing of seats on simple electro-hydraulic test rig (actively suspended seat with 2-DOF dummy is shown)

Cab floor vibration contains biggest components with frequencies in the vicinity of vehicle suspension natural frequencies, i.e. between 1.2 to 2.5 Hz, and from the acceleration point contains relatively important components between 1 to approx. 8 Hz. This is actually the frequency range, where the seat suspension is active (we are not considering seat cushion property).

2.2 Actively controlled air-suspended seat

General task on the seat transmissibility can be therefore posed. It demands achievement of amplitude transmissibility near or somewhat less to one at frequencies 0 to approx. 1 Hz and at least same or better than that of undamped passive 1-DOF at frequencies over approx. 3 Hz. This can be achieved with active control of the seat suspension only.

Development of actively controlled air-suspended seat for trucks and buses started at the Technical University in Liberec (TUL) in the year 2005.

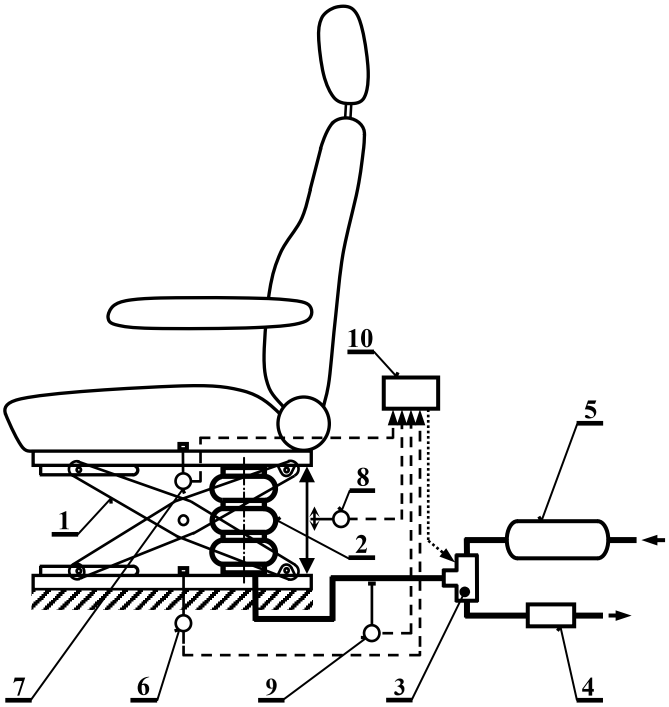

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Fig. 7 – General arrangement of the actively air suspended seat

General scheme of the control is shown on fig. 7. It uses signals from accelerometers 6, 7, displacement sensor 8 and pressure sensor 9 as inputs. Control computer 10 controls the position of the electro-pneumatic valve 3, which governs in– resp. outflow from the air spring 2. Use of any damping device is prohibited, as it would impair transmissibility at higher frequencies. Main problem lies in the use of air for working medium, because of its compressibility. Development of the control was already described in several publications [3], [4] and is not discussed here.

3. LABORATORY RESULTS

Laboratory testing of seats was done with seat base vertical movements, with artificial signals (harmonic, “chirp”) or, mainly, with signals gained by road measurements (many gained on TATRA proving ground). Seats were loaded by simple weights or by a 2-DOF dummy. Test results were however for simple weights and dummies very similar and their minor differences are not discussed here. Following results were gained with the dummy. Seat was excited by a quasi-stochastic signal Tatra. Input Tatra 1.5 is an increased input signal with analogical time course as Tatra.

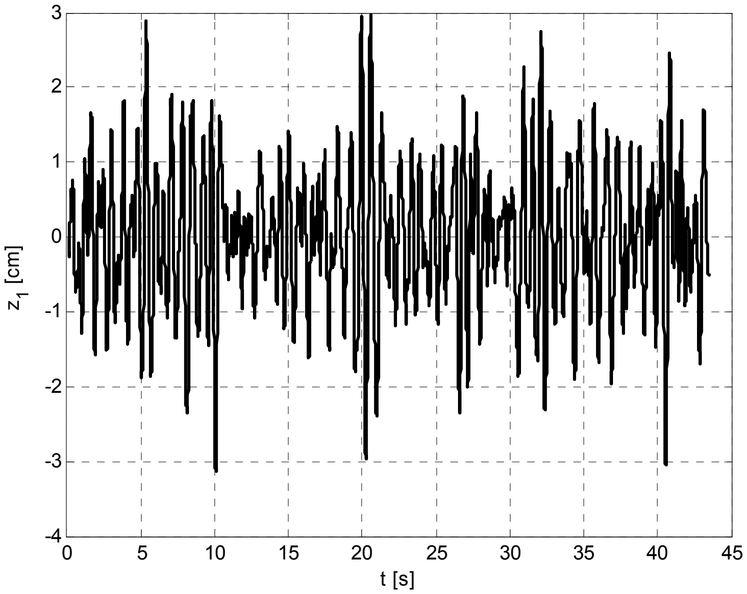

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Fig. 8 – Example of the seat base movement $z_1(t)$

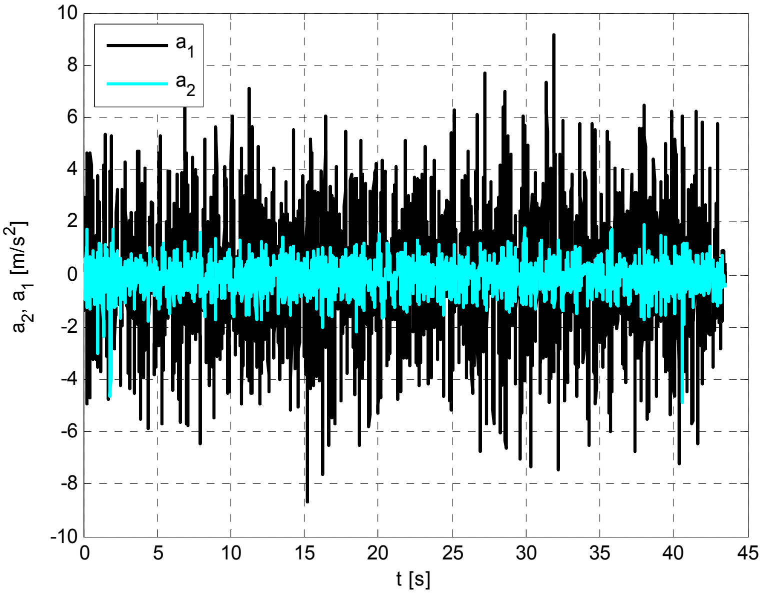

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Fig. 9 – Example of the seat base acceleration $a_1(t)$ and seat cushion acceleration $a_2(t)$

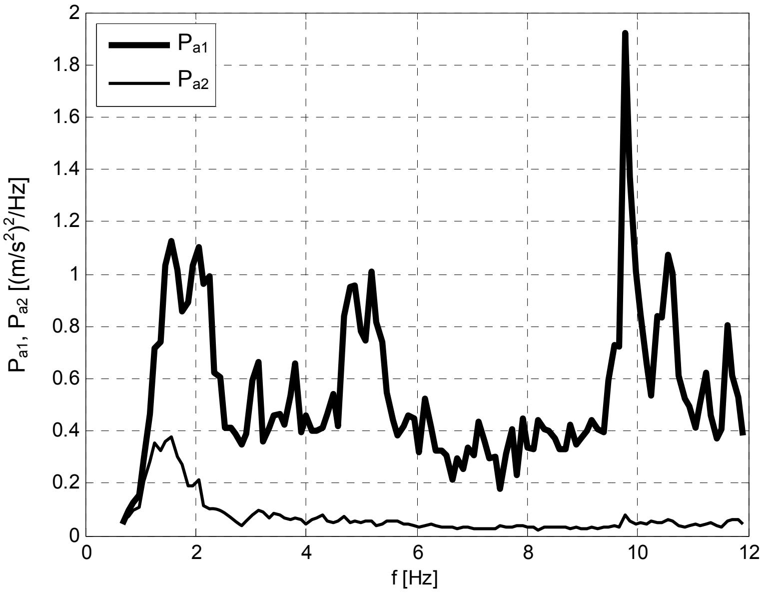

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Fig. 10 – PSD of the seat base acceleration a_1 and seat cushion acceleration a_2

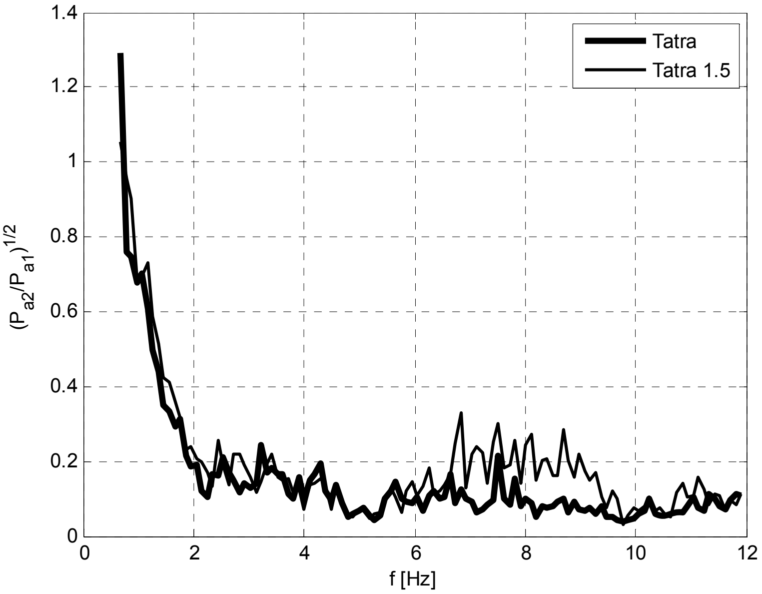

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Fig. 11 – Acceleration amplitude transmissibility

Results, gained in laboratory (figs. 6 – 12) indicate that the task of the development was fulfilled. It must be enhanced, that results shown are obtained using extreme input signals, very rough track signals, which are very rarely met in real vehicle service.

Experience gained during the development leads to the optimistic conclusion, that relatively big changes in seat transmissibility can be achieved by suitable seat suspension control even on air-sprung seats.

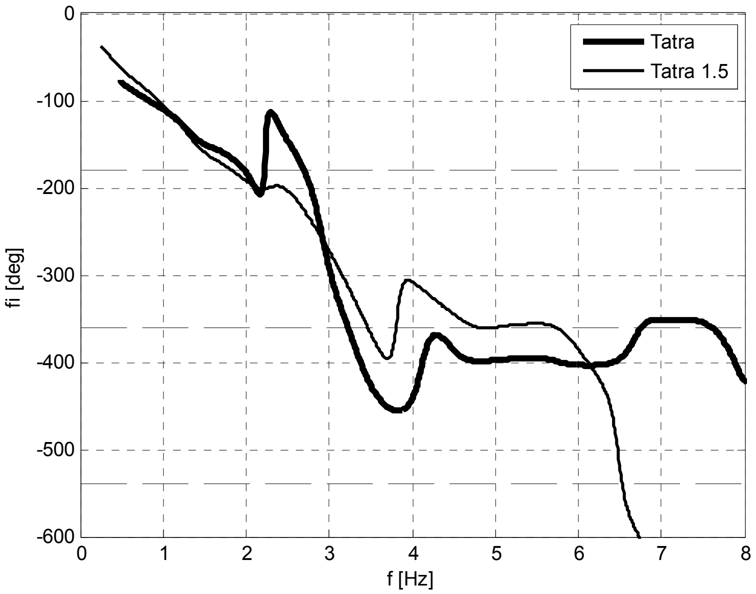

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Fig. 12 – Acceleration phase transmissibility

4. SEAT TESTING IN TRUCK

In-vehicle tests of the actively controlled seat TUL were conducted in the earlier stage of the development (figs. 13 and 14). Transmissibility of the tested seat was somewhat worse (fig. 15), than that gained in the newest stage, shown previously, but general development tasks were achieved.

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Fig. 13 – Testing of seats at TATRA proving ground

Though in-vehicle testing of the active seat TUL and of the passive seat were not carried out at the same time, vehicle, driver and tracks were identical.

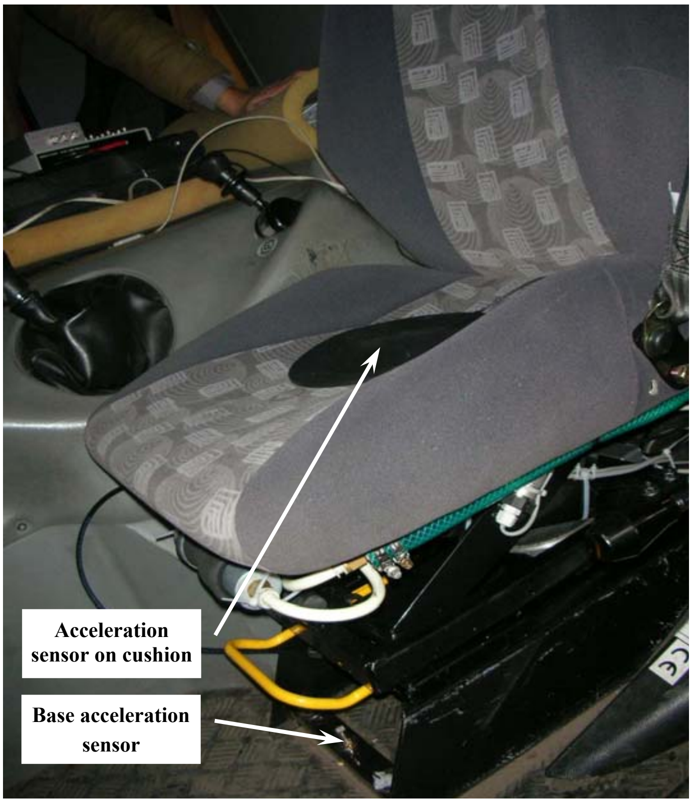

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Fig. 14 – Location of acceleration sensors during in-vehicle tests

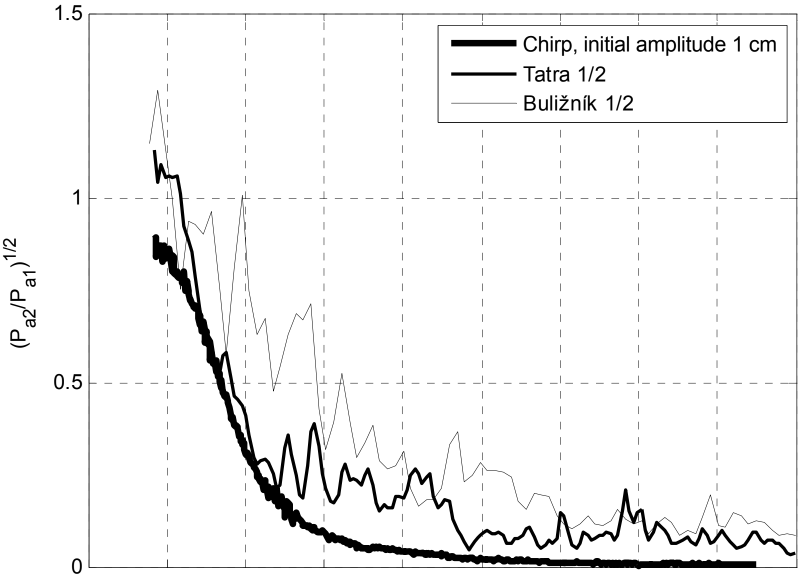

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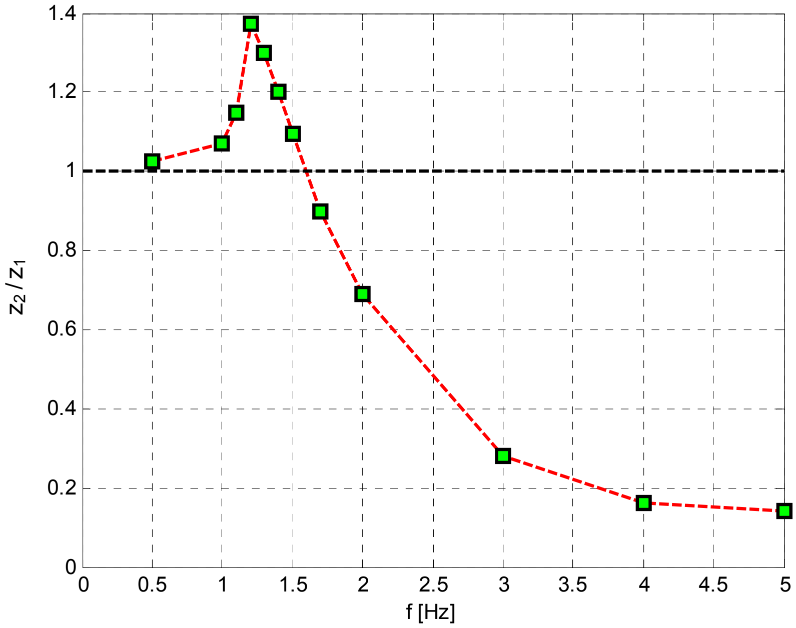
Fig. 15 – Amplitude transmissibilities of the active seat TUL of earlier development stage, gained in the laboratory with different input signals

Results gained on the test tracks with this actively controlled seat were compared with transmissibilities of a passive seat (seat B). In seat B was the air spring built inside the scissors mechanism in ratio 1/3. Seats were loaded by the vehicle driver in both cases.

Amplitude transmissibility function of passive seat B, measured by the vehicle producer, is shown on fig. 15. Course of the transmissibility, typical for passive seats, is evident.



Source: lit. [5]

Fig. 16 – Amplitude transmissibility of passive seat B gained in laboratory (unknown harmonic excitation and damping setting)

Transmissibility evaluation of the on–road experiments of passive and active seat led to somewhat unexpected results. Laboratory and in–vehicle transmissibilities were totally different not only on very rough roads fig. 17, but on good roads as well fig. 18.

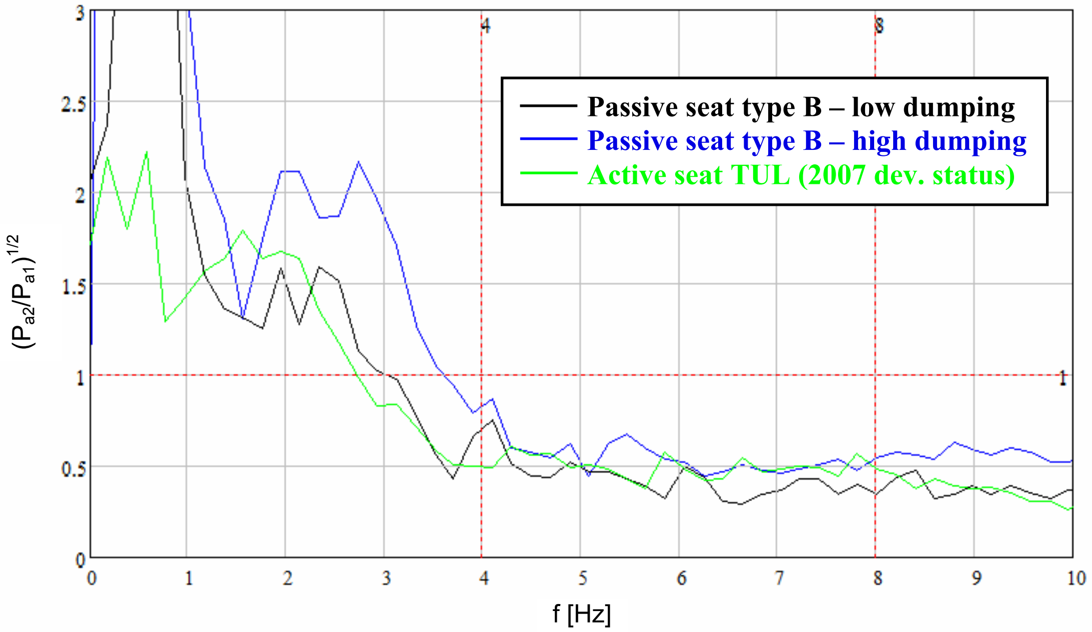


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Fig. 17 – Amplitude transmissibility of passive seat B and of active seat TUL gained on rough test track "Buliznik", vehicle speed 40 km/h

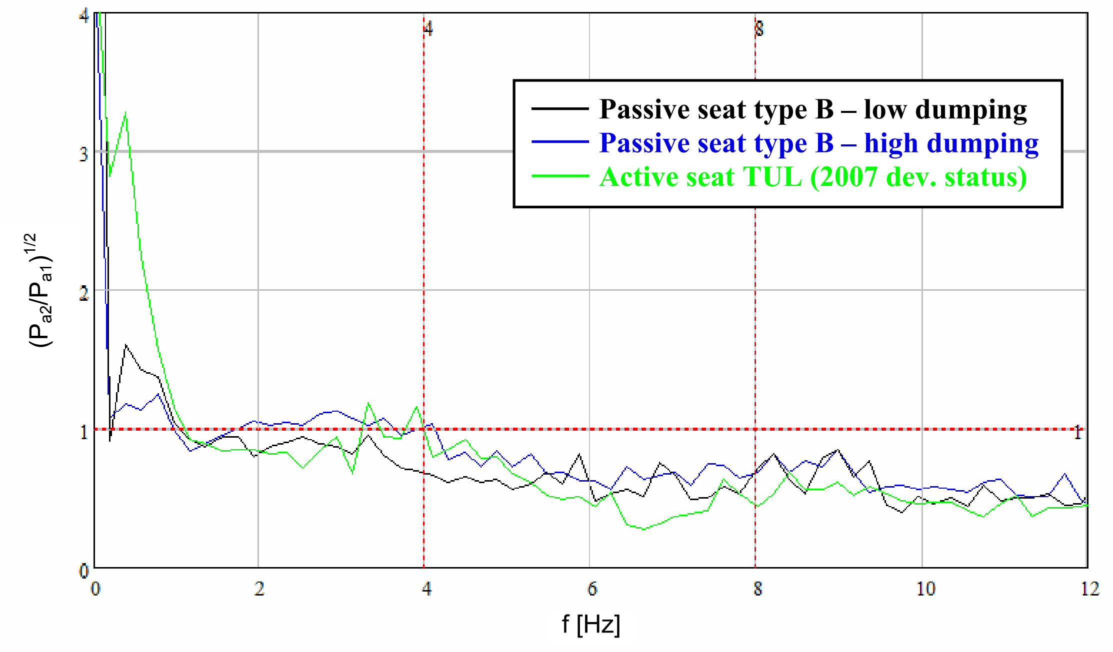

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Fig. 18 – Amplitude transmissibility of passive seat B and of active seat TUL gained on high road, vehicle speed 80 km/h

This can be clearly observed by comparing figs. 8 and 9 with figs. 17 and 18. Note not only completely different absolute values of the transmissibilities, but different courses as well.

It can be easily deduced, that this difference is caused by the influence of the person, sitting on the seat, in this case of the driver. This was not so unexpected on rough tracks, where driver must keep his position towards pedals and steering wheel, but was not, at least to such extent, expected on good roads.

Common evaluation of person's vibrational comfort on suspended seats by acceleration measurements and evaluation accordingly to ISO norm only evidently does not fully describe actual physiologic and psychic load on the person's organism.

Future development of actively controlled suspended seats must be therefore performed with active involvement of test persons. As in-vehicle testing is extremely time and money consuming (and therefore only very limited scope of tests could be done), future testing must be done in the laboratory.

5. CONCLUSIONS

Actively controlled seat suspension with very advantageous transmissibility was developed at the TUL. In-vehicle tests have however shown that laboratory transmissibility results, gained with passive seat load, are not valid for in-vehicle conditions, where person, sitting on the seat, is very actively governing his own motions. Developed suspension is therefore very apt for use in those cases, where passive persons are carried only, like for ambulance berths, etc.

Because of the flexibility of the control system, transmissibility of the actively suspended seat can be tuned to the actual demands of its passengers, if these demands will be known. Such laboratory research is in preparation at the TUL on a 6-DOF rig. Test rig, enabling motions of its platform in 6-DOF, was built and at time being tested in the TUL Hydrodynamic Laboratory.

6. ACKNOWLEDGMENT

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