REGULAR ADAPTRONIC PRODUCTS ENHANCED WITH THE FRACTIONAL ORDER CONTROL

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Abstract

Adaptronics is already present in many mechatronic products (e.g. agriculture, white goods), enhancing vibro-acoustic features in terms of comfort and product features without any substantial design modification. Comprehensive utilization of advanced adaptronics features (e.g. MR dampers) is possible fully to utilize only with proper process control. Here is suggested enhanced adaptronics features utilization with the fractional order control – fractio

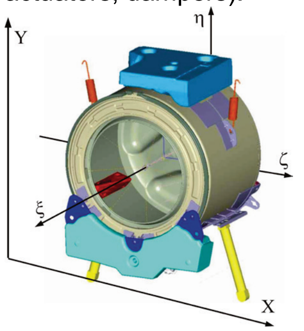
Keywords: Adaptronics, MR dampers, fractional calculus Fractional Order PID (FOPID)

1. Introduction

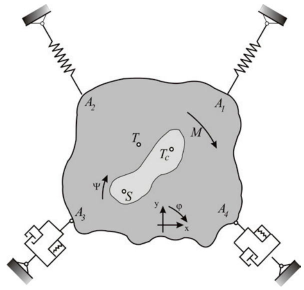
The control of the contemporary mechatronic product (e.g. agriculture, mechatronics) is very demanding task due the nonlinearity of multibody system, plethora of working profile/modes and rapid control response in shortest possible time. Besides the product features, there is also very demanding feature – comfort (e.g. ride comfort, noise level), which is influenced mostly by the outside factors – e.g. agriculture (uneven and rough terrain) and white goods (wet clothes distributions). Every technical solution has advantages and limitations, which should be taken into the account. Here is presented practical case from white goods and comparison of PID control – classical (non-fractional order) with advanced (fractional order).

2. Adaptronic system

The platform for the adaptronic system is always multibody system (MBS) behavior description (e.g. robotical approach – Rodriguez method), Fig. 1, which should be analyzed as the (non)rigid regarding working load program (modeling and evaluating the system response for (pre)defined excitation). This is crucial for further components selection (e.g. actuators, dampers).



a) *Tub assembly of washing machine with suspension*



b.) *Planar model - classical approach*

Figure 1. Multibody system – washing machine

There are many software (e.g. LMS, MSC Adams) as well as analytical tools (2D or 3D methods), which could enable designer quite reliable results for further product development. Main part of adaptonic system for vibration suppression is suspension system, Fig. 2.

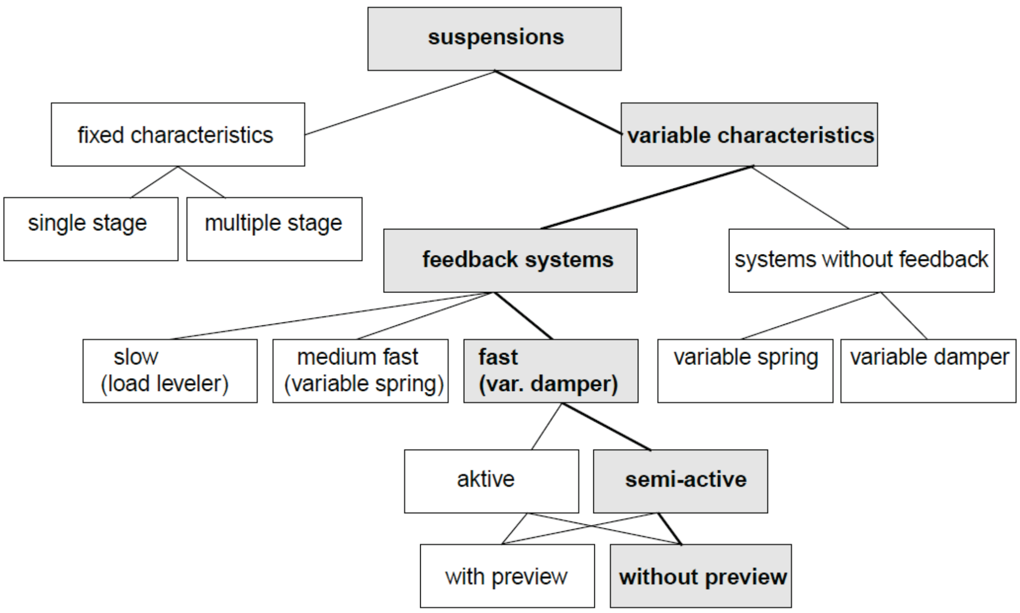


Figure 2. Art of suspensions and variable characteristics

The basic division is on the suspension with fixed and variable characteristics, where is the focus on the systems with the feedback information to the adaptronic system control (semi-active control).

The industrial solutions demands fast response and with the process preview/prediction, which is feasible with the sensor systems (e.g. aircraft landing gear, agriculture machine). The semi-active systems with the variable damping as fast feedback systems are mostly used MR dampers (magnetorheological damper or magneto-rheological shock absorber). Such dampers, as part of adaptronic systems, have proven itself in past two decades as advantageous in terms of the vibration and noise suppression. There were also very soon applications in white goods industry with modeling and experimental tests in various countries in Europe (e.g. Sweden, Turkey and Serbia). Another issue has been also suspension properties deterioration due the ageing and wearing out during the exploitation.

The MR damper used (in our case as part of experiment) is adaptive damper (LORD RD 1005-3), which damping capability is controlled/changed by the current, Fig. 3.

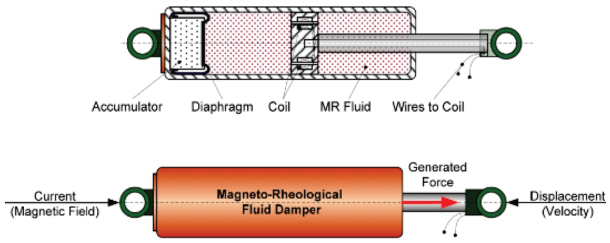


Figure 3. MR damper (LORD RD 1005-3)

The MR damper has in the tube MR fluid contains 20-40% by volume of relatively pure, soft iron particles, e.g., carbonyl iron with consistency similar to that of motor oil. Due the presence of an applied magnetic field, the iron particles in suspension acquire a dipole moment aligned with the external field which causes particles to form linear chains parallel to the field. With solidification of the suspended iron particles is restricted the fluid movement, which could occur in few milliseconds.

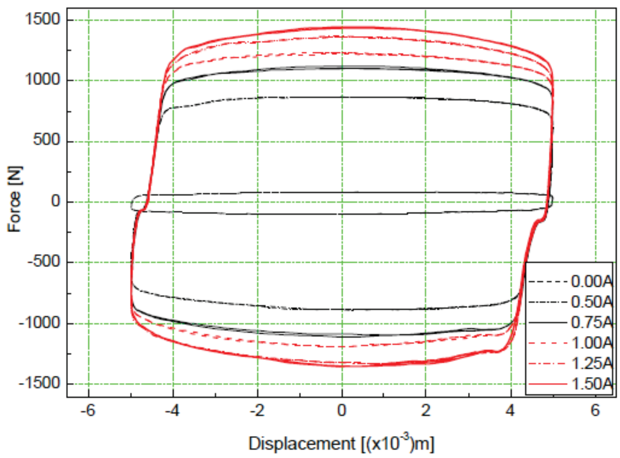


Figure 4. MR damper – response diagram

The control of the damping properties are conducted with the control unit supplying the current (from 0A up to the 2 A), which causes substantial difference in response, Fig. 4. The level of distance or vibration amplitude is the correlated with the level of supplied current to the damper. This response diagram is therefore modified by the process control unit, which correlates many sensors and performance indexes (e.g. as non-dimensional evaluation criteria – peak-to-peak or RMS criteria).

Prior experimental work, there could be also done some predictive modeling of MR dampers upon known MR models (e.g. Bouc-Wen, Bingham model) for certain load profiles to determine overall system response.

3. Process control system

Understanding each component's feature, there is easier way to design process control system with the controlling parameters – measured with the sensors or being non-dimensional as derived values from the system behavior.

Based on the type of the suspension system and the adaptive damper system, we could therefore design the process control system, semi-active, Fig. 5.

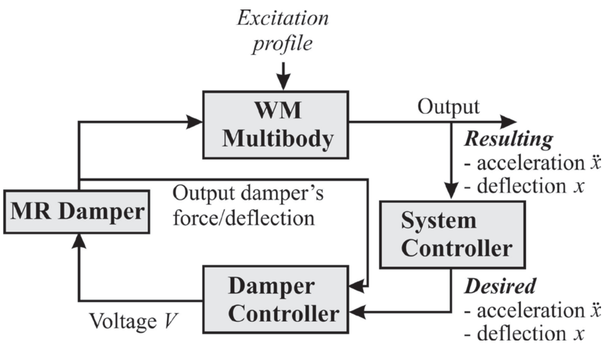


Figure 5. Semi-active control scheme with MR damper for washing machine (WM) multibody

The excitation profile or working profile/load is actually same for the various multibody systems (e.g. tractors, trailers) and represents desired working mode/track.

The resulting values for control are either outer system response (s.c. resulting deflection) which are then modified by the central control unit (s.c. system controller) and pass information to the suspension (damper) controller with its own control loop.

There are many industrial approaches for the semi-active control – like - Skyhook, Groundhook, Hybrid Control, Displacement Skyhook Control, Relative Displacement Skyhook Control, Current Driver Circuit, On-off balance and continuous balance control algorithms.

For all (semi-active) control approaches, there should be the same evaluation for different modes (working profiles) or excitation – the most often it is – single frequency (harmonic) excitation, impulse excitation, transient excitation or hybrid excitation.

Naturally, there should be also response analysis for the control approaches and the excitations (e.g. frequency response, wavelet analysis)

Main issue for all above named (semi-active) control – they all have advantages or disadvantages – e.g. limited performance for impulse excitation or for the transient excitation.

We care here about the dynamic behavior of a system (adaptronic product) and then we are not handling a problem of simple logical control (e.g. traffic lights turned on and off) in a negligible time.

The dynamic behavior of the plant is very important and this behavior is usually described by differential or difference equations. Very often such equation, describing the system includes derivatives whose order is not an integer number. Therefore, we are dealing with the fractional order systems, which are described by the fractional differential equations.

Consequently, a control algorithm for the fractional order is recommendable to have also dynamic behavior described by fractional derivatives too.

The usual approach of control that uses of integer derivatives only is therefore a particular case of fractional control (a generalization thereof).

The fractional calculus and related fractional calculus is also applicable for the adaptronic dampers ((MR) magnetorheological and (ER) electrorheological) to describe the realistic phenomena with less (calculus) aproximations.

The advantage of fractional order PID in comparison to the regular or non-fractional PID is well known and already proven for many actuators (e.g. DC actuator).

On the other hand, there is already done some hardware in loop (HIL) simulation for the system, described with the fractional order derivate (within NI Labview).

4. Problem statement

Main issues, which have to be addressed for successful system description and control:

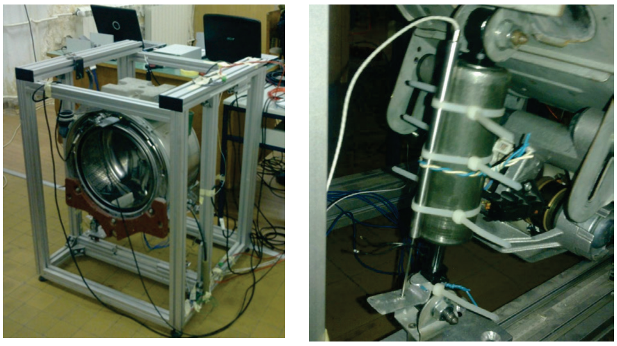
- Excitation profile and related system response – e.g. impulse, step or steep excitations;
- Components description with the fractional calculus (e.g. MR damper, actuator, control);
- The overall control system design/strategy – sensors, actuators and vibration suppression;
- Identification of the fractional derivate for the system component as well as overall control;
- Modeling and simulation prior experimental verification;

Namely, despite the advantage of fractional calculus approach in comparison to the non-fractional calculus – there is need to validate each system's subcomponent or set of subsystems.

5. Some past experimental results

There have been done some experiments on the washing machine with adaptive (MR) dampers and comparison with the (classical) dampers for the various excitation or working profiles.

The experimental setup, Fig. 6, has enabled us to validate some of the theoretical simulations – especially in terms of the accelerations or forces and the (orbital) path).



a.) *Experimental setup* b.) *MR damper - LORD*

Figure 6 - Adaptornic system – experimental setup and MR damper

The experimental setup (Figure 6) consist on:

- <u>system excitation</u> – electronic controller for actuator;
- <u>system measurement</u> – displacement sensors (LVDT), Fig. 6b, acceleration (accelerometers), force (strain gauge)
- <u>suspension control</u> – control the adaptive – MR damper;

Main issue is to harmonize the control of system with the MR damper's force control in order to achieve main effect – more effective damping and less excessive vibrations, Fig. 7.

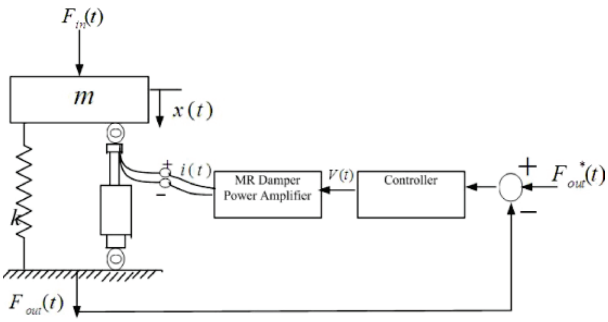


Figure 7. Simple MR damper control

The "preview" sensor (like in Fig. 1) for the effective MR damper's force control (like in Fig. 7) would be displacement sensor (LVDT). Upon the displacement, the time delay process control with the adaptive dampers as well as the process control parameters would enable effective damping and limit excessive vibrations (consequently also noise). Certain limitation is also ability the time response of the MR dampers for quick value changes as well as durability.

Here are also some results of the simulation and experimental work – for MR dampers as well as for the fractional order control (FO PID), Figs. 8-10.

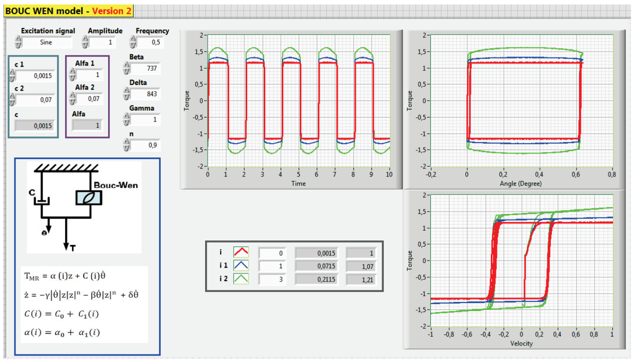


Figure 8. Simulation in LabView – Bouc-Wen model – MR damper

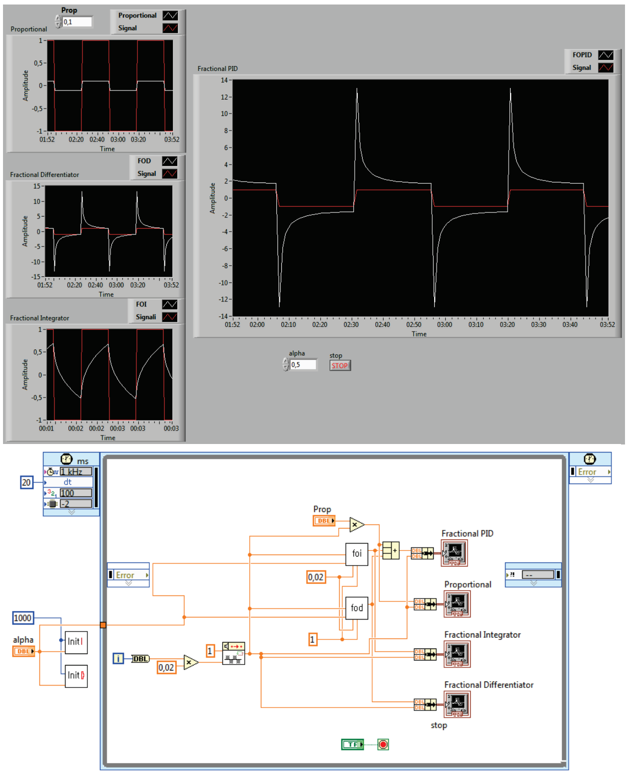


Figure 9. Simulation in LabView – Fractional Order Control – FOC PID

Simulation results for FOC PID enabled sweeping various parameters – as (ideal) harmonic function or even the impulse and adjust FOC parameters.

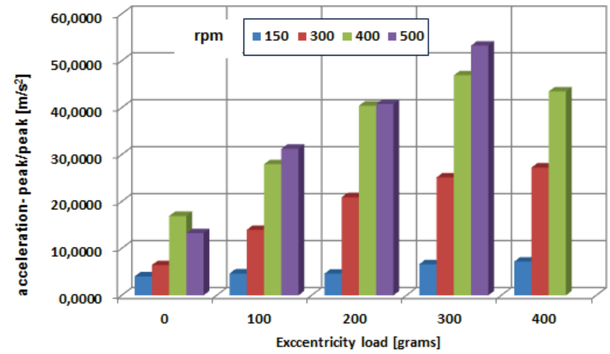
These were set by the equations as transfer function in *s-* domain:

$$C(s) = U(s)/E(s) = K_p + T_i s^{-\lambda} + T_d s^{\delta} \quad (1)$$

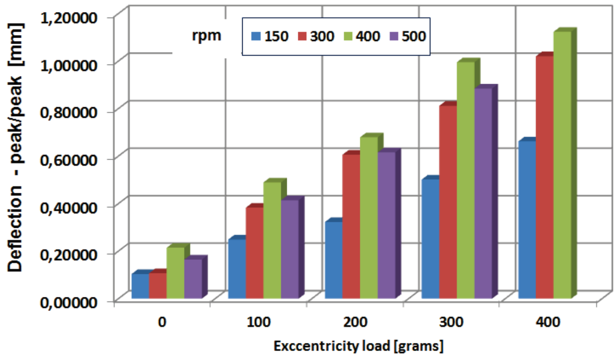
and time domain

$$u(t) = K_p e(t) + T_i D_t^{-\lambda} + T_d D_t^{\delta} \quad (2)$$

Some experimental results have also been gained in the past as part of the experimental setup design, load ("excentricity") upon different excitations, resulting deflections and accelerations, Figs. 6 and 10.



a.) Acceleration



b.) Deflection – peak/peak

Figure 10. Experimental results with adaptive dampers

6. Proposed solutions and guidelines

Main issue to conduct the adaptronic system modelling for further enhancement is to assemble the simulation model of adaptronic system (some call it mechatronic) as a multiphysical system - to interconnect the simulation models of particular subsystems of certain physical nature into one resulting multiphysical (multidisciplinary) modeling, Fig. 11. There are two different approaches, <u>*co-simulation*</u> (tight and weak coupling) and *uniform modelling with different formalism* - equations (algebraic, differential), dynamic blocks, multipoles and bond graphs. Nevertheless, the natural basis of simulation models of adaptronic systems are the multibody models that are feedback controlled, where the mathematical models and corresponding simulation models are being developed for systems from one physical domain. After modeling, simulation and control synthesis - the designer has to proceed with the final stage, hardware in loop (HIL) simulation. Namely, without the real time simulation with actual analog and digital signals the adaptronic product could not be properly validated. In the HILS the stepwise transition from the pure model representation of the adaptronic system to actually mounted mechanical, hydraulic and electrical components takes place.

The modular modeling has to include advanced control strategy, like fractional controllers – e.g. fractional PID.

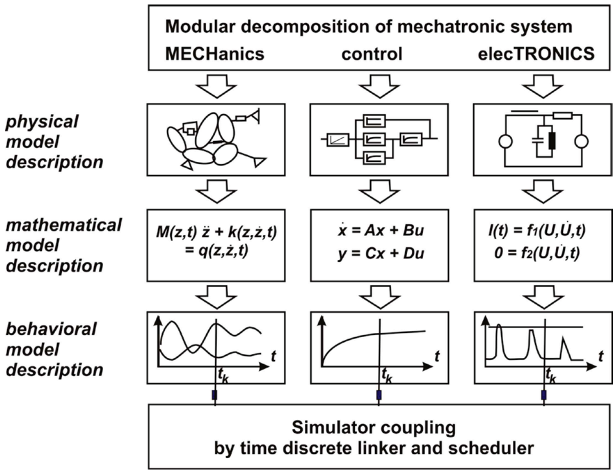


Figure 11. Modular modeling and simulation – adaptronic system

7. Conclusion

The real task system control solutions in the industry are very often quite rigid and rely on the simple ("recipe") solution. On the other hand, the system optimization is also tackled partially (e.g. only the actuators or dampers optimization) and could not substantially enhance the (adaptronic) product. The solution is in the overall adaptronic system modeling with s.c. HIL approach and to implement advanced fractional order controllers.

8. Acknowledgement

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