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ABS VALVE MODEL REDUCTION BY AMESIM

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The aim of the paper is to build and validate a model of ABS/ESP valve with LMS Imagine.lab-AMESim. A good functional model was obtained by reducing the initial complex model using different model reduction tecniques like activity index and state count. Different levels of valve models were considered in order to keep the time continuity and to evaluate the simplification techniques. Both steady-state and dynamic model behavior were validated by experiments.

Key words: ABS system; Swiching valve; Model reduction; Modeling; Simulation; Activity index; State count.

1. INTRODUCTION

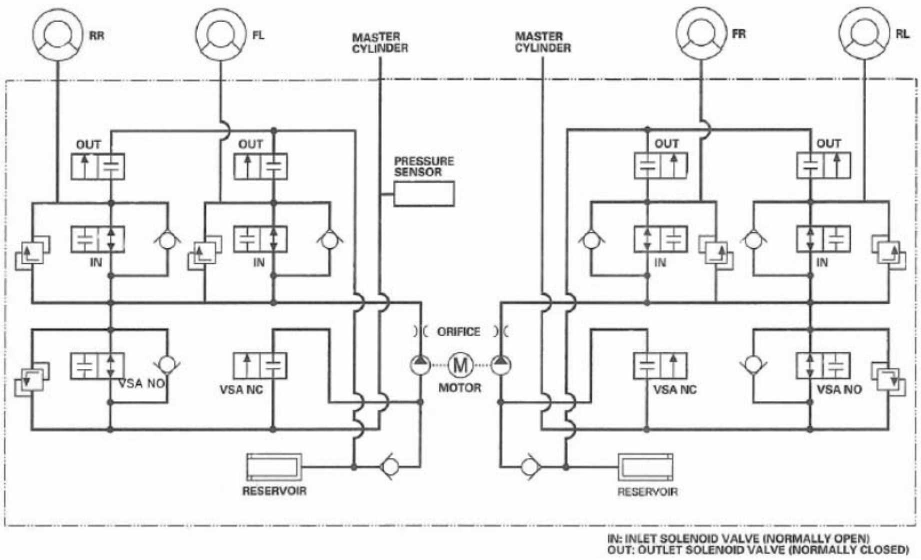
The ABS was introduced for the first time in airplain industry, early in 1929. For the road vehicles the real development was made after 1980 and since then a series of improvements were made to bring this system, in our days, to be equiped on almost all the road vehicles as a necesary safety system. Generally speaking the ABS offers improved vehicle control but in some circumstances this system could have also some disadvantages including increased braking distance on slippery surfaces such as ice, snow, steel plates and bridges. Recent versions of ABS not only prevent wheel lock under braking, but also electronically control the front-to-rear brake bias. This function, depending on its specific capabilities and implementation, is known as Electronic Brakeforce Distribution (EBD), Traction Control System (TCS or ASR), Emergency Brake Assist (BA, EBA or HBA) or Electronic Stability Control (ESP, ESC or DSC).

A recent study shows that the ABS has reduced the risk of multiple vehicle crashes by 18 % and the risk of run-off-road crashes by 35 %. The evolution of the anti-lock braking system and implicit a high security level on roads was not possible without modeling the ABS and building virtual models that allow a detailed analysis of every system component.

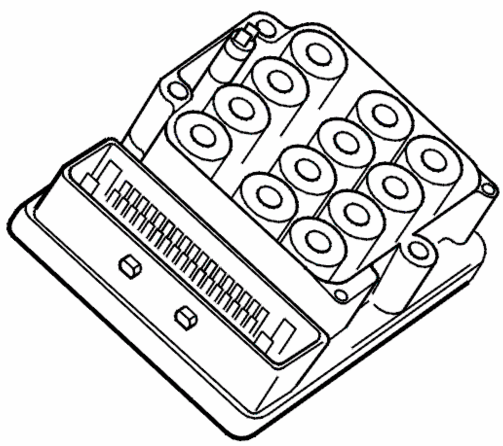
Using simulation software is very easy to build a multi energy domain system (like ABS) with a very high complexity level. Effective design of complex systems requires simple models. As a consequence, the most difficult aspect of synthesizing a model is to figure how many physical effects (inertial, compliant and dissipative elements) are needed to adequately represent the real-world phenomena under study. This leads to the notion of the necessary and sufficient complexity for the final goal.[1] Proper models are defined following the next hypothesis: the model must have physically meaningful parameters and state variables, the model must have the minimum complexity required to address the modelling objective. Proper models contain the minimum information needed to show the relationship between the design parameters and the dominant system dynamics and preserve the physical meanings of their structure and parameters. The physical meaning is essential from the engineering point of view. [1] Several methods concerning the utilization of decision support systems (DSS) in the reduction of large-scale complex systems (LSS) are proposed by Filip.[2]

An ABS block is essentially made of several types of pressure control components. Merritt [3] and Vasiliu [4] offered a generic approach of the pressure components. Merritt has given some complementary analyses of the stability and the dynamic behavior, and Vasiliu used numerical simulation for time domain analysis of the pressure control components.

In this paper some model simplification techniques is emphasized for a single ABS valve. The virtual model is created with different levels of complexity, and the final simple model is validated by experimental data for later use in HIL applications (Hardware-In-The Loop Systems Simulation).



a)



b)

Figure 1. ABS structure: a) hydraulic circuit; b) valves solenoids block for TRACS/STC/DSTC

2. MATHEMATICAL REVIEW OF THE VALVE MODEL

The model of the poppet ball valve with conical seat from the Hydraulic Component Design library is shown in the figure below and using this model the ABS valve was built. In this case, this is a normally open valve. The minimum flow area is the curved surface of a truncated cone. It is important that the condition $\Phi + \theta < 90°$ must be observed where $sin(\Phi) = ds / db$ or the ball cannot rest on the conical seat. If this condition is broken then the situation is treated as a circular hole seat. [5]

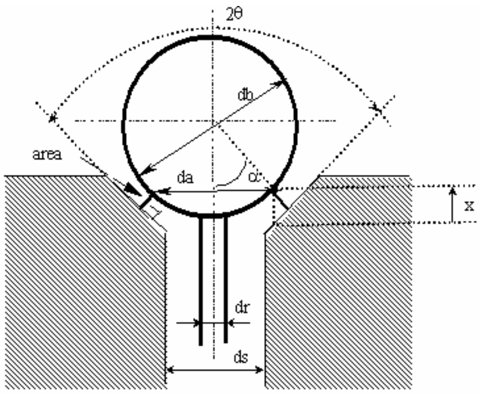


Figure 2. Poppet ball valve

The orifice area is

$$area = \pi \cdot x \cdot (db + x \cdot \cos\alpha) \cdot \sin\alpha \cdot \cos\alpha$$

where θ is the seat semi-angle

$$\alpha = (\pi / 2) - \theta$$

and *db* is the diameter of the ball. The hydraulic diameter is

$$dh = \frac{4 \cdot flowarea}{flowperimeter} = 2 \cdot x \cdot \cos\alpha$$

with the active diameter

$$da = db \cdot \sin\alpha$$

The internal value used for x is limited to a lower value of xmin and an upper value of min(xmax,xlim) where xlim is the lift at which the calculated area becomes equal the annular area

$$\pi \cdot x \cdot (db + x\lim \cdot \cos\alpha) \cdot \sin\alpha \cdot \cos\alpha = (\pi / 4) \cdot (ds^2 - dr^2)$$

The volume of fluid *vol* subject to the throat pressure additional to the volume at zero lift is

$$vol = \frac{\pi}{4} \cdot x \cdot (da^2 - dr^2) + \frac{\pi}{2} \cdot x^2 \cdot \sin\alpha \cdot \cos\alpha \cdot \left[da + \frac{2 \cdot x \cdot \sin\alpha \cdot \cos\alpha}{3} \right]$$

These volume changes are important if pressure dynamics is calculated (frequency analysis). Finally the derivative *dvoldx* of *vol* with respect to *x* is calculated. This may be used to obtain an equivalent flow rate:

$$q = dvoldx \cdot \frac{dx}{dt} \cdot \frac{\rho(p)}{\rho(0)}$$

where *dx / dt* is the velocity of the poppet.

3. MODEL SIMPLIFICATION TOOLS

A possible idea for model simplification is to use the power exchanges between system parts. Well known is the fact that components associated with low power flow makes small contributions to a systems dynamic behavior. This concept is called the *activity index* and was introduced by Louca. [6]

$$A = \int P(t)\, dt$$

where P(t) is the power. The idea behind the absolute value is to store whatever the exchange is. The activity index is just the activity of an element divided by the total amount of activity in the system.

Activity index of inertial, dissipative and compliant elements is a standard feature of the LMS Imagine.lab AMESim software, and can be used for model simplification. Using activity index the most energy active components of a system and the most energy passive components can be identified.

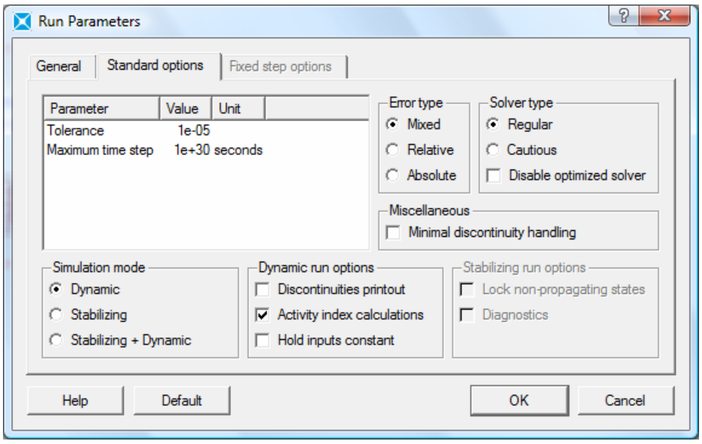


Figure 3. Activation of Activity index

Another tool for model simplification that is implemented in LMS Imagine.lab is *state count.* The main purpose for this facility is to identify the reason for a slow run. In the state count window the elements that induce the biggest effort for the integrator can be seen.

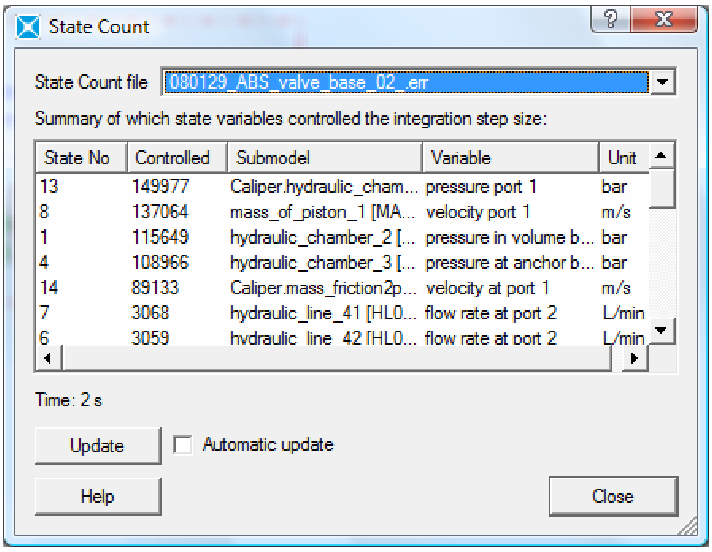


Figure 4. State count window

4. ABS VALVE MODEL SIMPLIFICATION

In a first step a detailed model of the ABS valve was built using components from the Hydraulic Component Design (HCD), Mechanical, Hydraulic and Signal Library. This complex model requires geometrical parameters like the mass of the spool, the diameter of the piston, diameter of internal fixed orifices, angle of cones, spring stiffness and preload. No electric circuit will be used for the model so the hysteresis of the solenoid will not be considered. Therefore the control of the valve will be made using a 2D table which represents the characteristic $F = f\,(Current,\ Displacement)$.

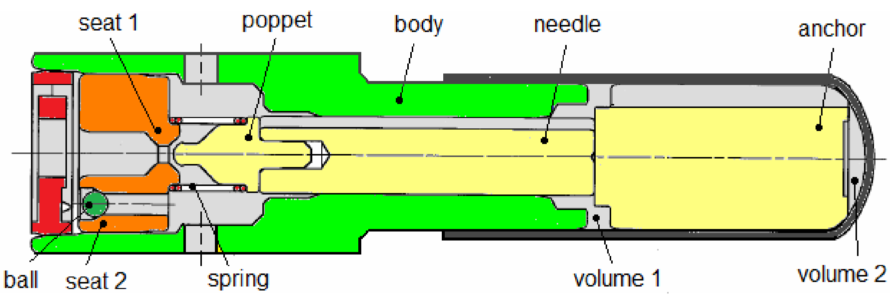


Figure 5. ABS valve sketch (without solenoid)

The inputs for the model are the master cylinder pressure, the calliper pressure and the current used to pilot the solenoid. This current is a function of the calliper pressure. If the calliper pressure reaches 140 bar then the valve will be closed. The current will rise from 0 to 2A which represents the closing valve current value. The methods to obtain simple but proper models are divided, as mentioned in [6], in three main categories: a) methods based on the mathematical manipulation of the system's input-output relations; b) methods based on physical interpretation of the system's dynamic behavior; c) the combination of a) and b) [7]. The models from the first category are based on transfer functions and they are mostly used for "linear" systems, and in general the physical sense of the state variables or the parameters is lost. However for multi-domain systems including hydraulics, the dynamics can vary enormously during the simulation, hence this technique is not well suited [1]. The second category uses procedures involving power exchanges between parts. Pressure components are always used in hydraulic circuits and thus have been widely analyzed for the stability [3]. They can be viewed as multi domain components involving hydraulic, mechanical, and sometimes electro mechanical devices.

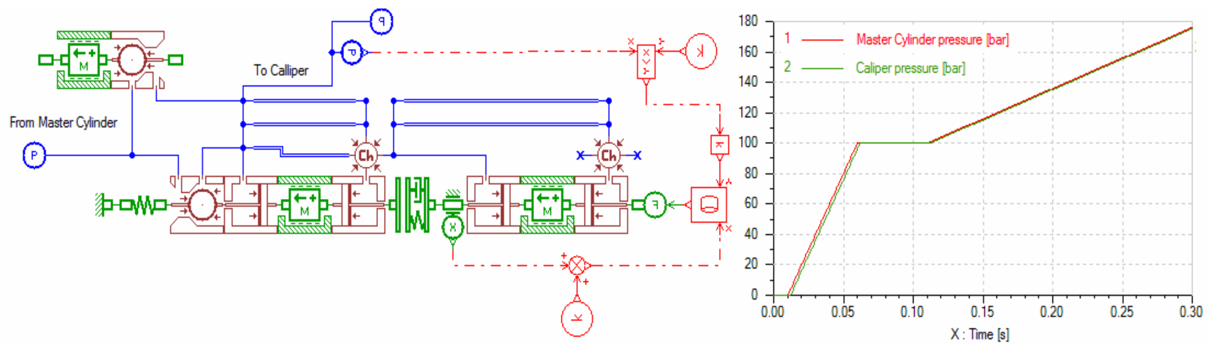


Figure 6. ABS valve complex virtual model and the model inputs

As it can be seen, the first model of the ABS valve (fig.6) is built using components from four libraries: hydraulic, hydraulic component design, mechanical and signal. A first analysis of the Activity Index shows what component of the model have low energy contribution to the system dynamics. Those components should be taken into account for model reduction. Before reducing the model the State Count facility will be used as a complement to the Activity Index. From the Activity Index analysis results that the hydraulic lines (both inertial and dissipative elements) have a low energetic contribution to the system dynamics. Also the hydraulic chambers (compliant element) have very small contribution. The hydraulic part of the anchor can be also reduced (as the pressure from left and right of the anchor are equal).

Care should be taken when using the Activity Index facility because this tool may give a wrong answer if the power in the main circuit is very large compared to the power used to pilot the ABS valve. The main circuit and the pilot circuit should be simplified independently or better said one element of these two parts should remain in order to give access to the right behavior of each. The first level of simplification is presented in figure 7.

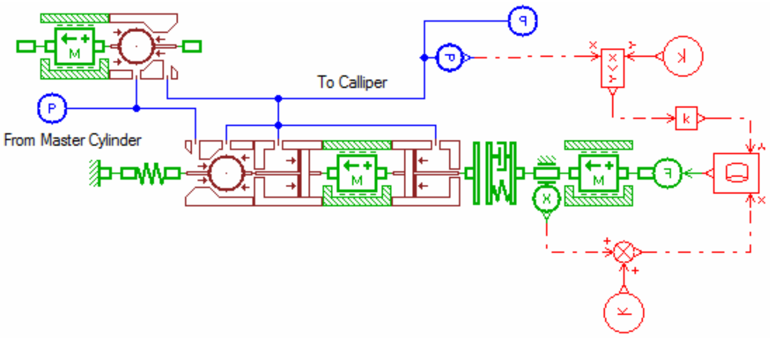


Figure 7. ABS valve first level of simplification

Care should be taken when using the Activity Index facility because this tool may give a wrong answer if the power in the main circuit is very large compared to the power used to pilot the ABS valve. The main circuit and the pilot circuit should be simplified independently or better said one element of these two parts should remain in order to give access to the right behavior of each. The next two levels of simplification were done using the same technique. In the end (fig.8) the model was reduced from 13 state variables to 1 state variable. The CPU time was reduced from 18,5 seconds to 0,013 seconds. The final model can be built using real time compatible elements and it can be included in a HIL application.

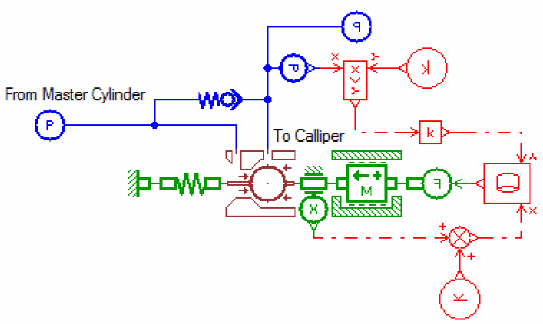


Figure 8. ABS valve final simplified model

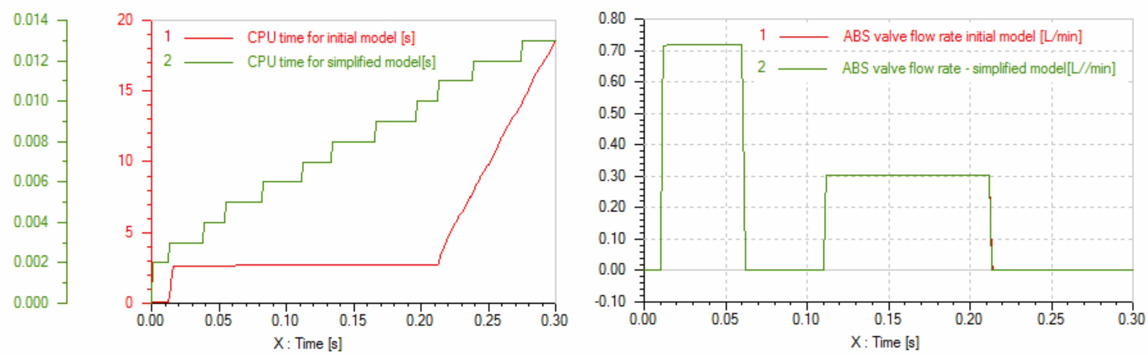


Figure 9. Results comparison

5. STEADY-STATE AND DYNAMIC MODEL VALIDATION

In this part of the paper a validation of the previous model was made using experimental test bench data. The models used for validation were built with the test bench specification and parameters. The variation of pressure versus electrical current of the solenoid represents the steady-state characteristic from the test bench. A calliper model is also used for valve validation. From the plot below it can be seen that from steady-state point of view the virtual valve model is accurate enough.

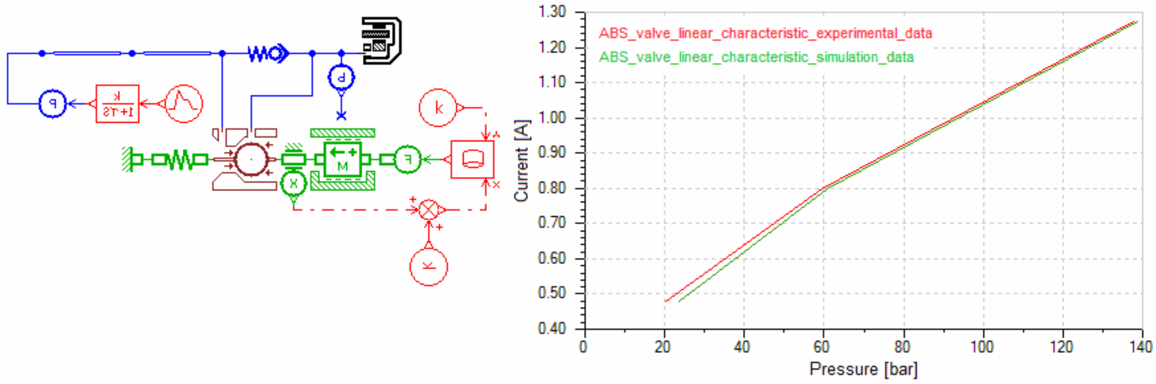


Figure 10. Steady-state model validation

For dynamic validation another model is built. This new model contains also another valve and a calliper in order to observe the pressure rising in the calliper cylinder. All the hydraulic lines used in this case have the same parameters with the real hydraulic lines used on the test bench. The components from this model are specific to real time applications and can be included in a global model of ABS that can be used in a HIL phase. The pressure rising versus time is the characteristics of interest in this case. It can be seen from the results analysis that the ABS valve virtual model gives results that are slightly different in the middle part of the pressure rise, but the beginning and the end are the same. It can be concluded that the ABS model gives satisfactory results in comparison with the test bench experimental data. [8]

6. CONCLUSIONS

The cost and time associated with building and testing prototypes are less and less tolerated. The use of modeling and computer simulation is today alternative to reduce design cycle time and implicit to reduce costs. Building virtual models and making them a solution to evaluate the design decisions is what is happening today not only in the automotive industry but in all industries. An important factor is the creation of functional models that are really accurate in comparison with the real phenomena. This paper was focused on model reduction techniques and in the end a validation of the model was made using experimental data.

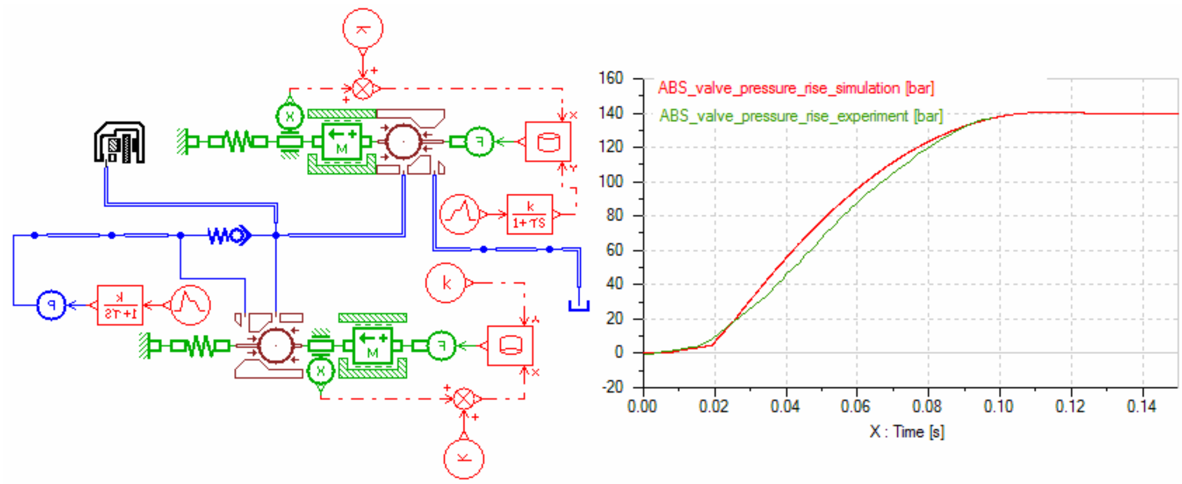


Figure 11. Dynamic model validation

There are a lot of possibilities to build a simplified model and the software should allow continuity in model simplifications. This means that software should give access to all causalities for all physical effects. The engineer that build the model should have all the time in mind the assumptions made for every level of simplification. Care should be taken about storage elements since they lead to implicit loops if they are not reduced.

The activity index as well as the state count facilities are of great help to simplify a model since the first gives an aspect of power, and the other **-** the difficulty the integrator has to satisfy its error criterion leading to a variable corresponding to a high frequency.

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