Dynamic Analysis of a Hydraulic Drive for a Lifting Bridge

Uwe Grätz

ITI GmbH, Webergasse 1, 01067 Dresden, E-mail: Graetz@itisim.com

John Garret

Hunger Hydraulic UK Ltd., UK

Abstract

Large applications in field of hydraulic steel construction are mostly driven by oil hydraulic systems. Especially in case of bascule bridges the small required space for hydraulic cylinders is an advantage of this technology. Because of the influence of such kind of civil engineering products to minimum two crossing traffic flows there are increasing requirements to fulfill limited opening and closing times. Connected to this the acceleration during start and stop procedures becomes higher. The dynamic behavior and properties of the hydraulic drive connected to the mechanical system is more and more important. Owner and manufacturer of such kind of bridges are interested to see the required and convenient behavior before realization. This presentation shows the complete process beginning with the task, derivated from the requirements of the bridge designer, the development of system and component level models and the results leading in some hints for circuit design. Very helpful for the solution is the possibility to consider hydraulic system models connected to 3D mechanics.

KEYWORDS: hydraulic system design, simulation, SimulationX, bascule bridge

1. Introduction

Object of the Analysis is the hydraulic drive system of the new bascule bridge of Poole Harbour. The bridge will improve the traffic situation around the harbor. The bridge has two leafs with a special design.

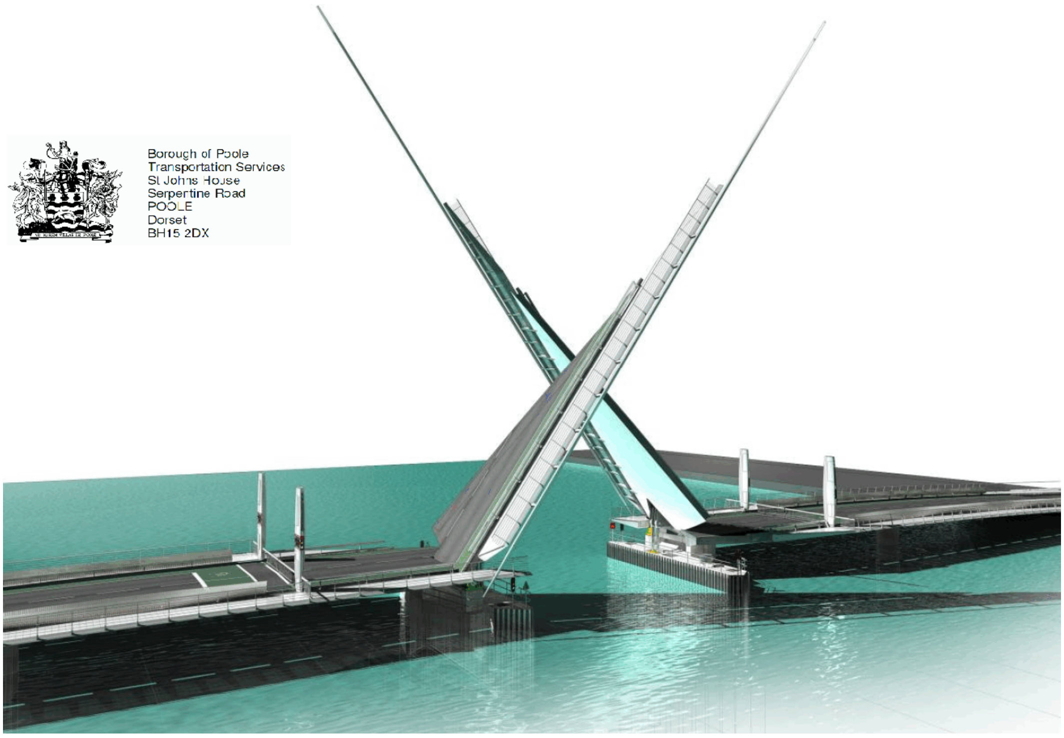

Figure 1: Design study of the bridge /1/

The leafs of the bridge are driven by hydraulic cylinders – two per leaf. Each of both cylinders has a manifold to provide functions for movement control, stability and safety. The two cylinders of each side are supported by hydraulic power pack with one pump per cylinder.

The simulation task should support the dimensioning and setting up of the hydraulic system. With help of dynamic simulation the stability of the behavior should be shown.

For this analysis tasks a simulation model was created. The model contains the important components and properties. The mechanics part, necessary for hydraulic model is a simplified one. Furthermore different external excitations and loads have to be considered.

2. Model Description

2.1. Mechanical System

For modeling the mechanical system 3 dimensional properties should be considered. The modeling task was done with the well-known system simulation tool SimulationX. The simulation software allows considering 3D mechanical components to be connect to the hydraulic cylinders. This option is used to model the bridge kinematics.

2.1.1. Structure and static loads

At first a model considering static loads and rigid mechanics was created. With this model all kinematic conditions, masses and external loads were well integrated, parameterized if known and tested.

The mechanical system is modeled with a rigid bearing, a rigid body with one part of the leaf. The geometric conditions were read from the delivered drawings.

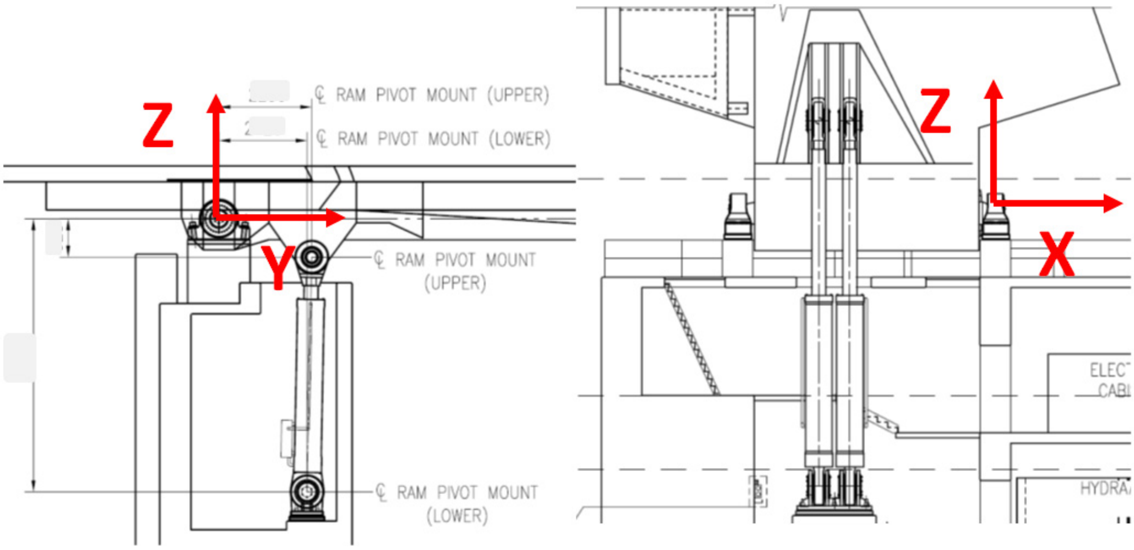

Figure 2: Geometry of bearing and cylinder and coordinate systems /1/

With these information the mechanic structure was modeled. The leaf was considered as a CAD import element to have the complex geometry, the location of the center of mass and also inertia data in the model.

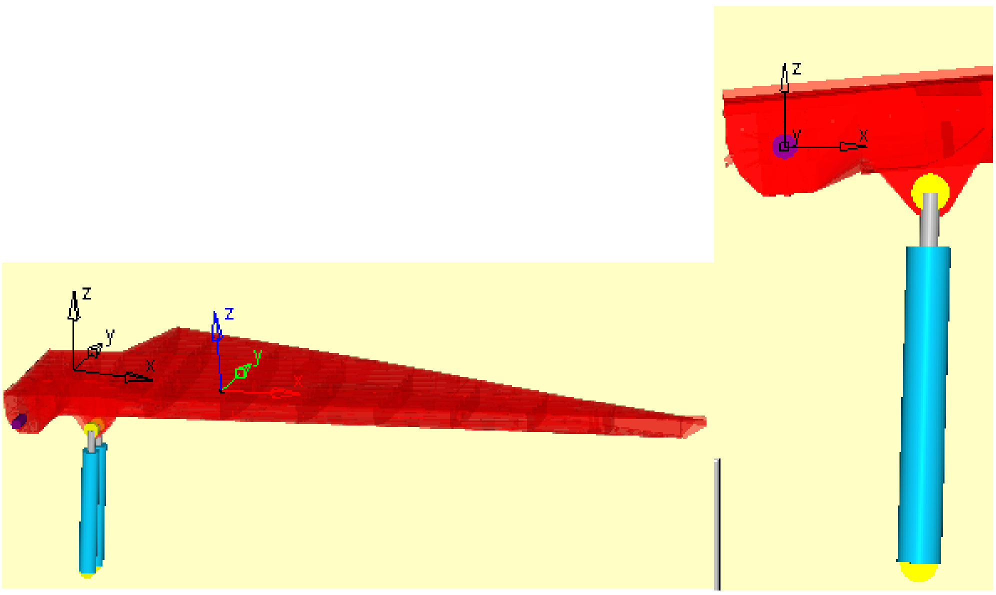

Figure 3: Integration of the complex leaf geometry

The topology of the first model is shown in **Figure 3**. The aim with this model is to check the static loads given from client. Part of such kind of analysis is always calculations with different external loads like wind loads of different level and direction and in this case snow loads also. The model was used to check and to convince the customer of correct consideration of mass and external loads.

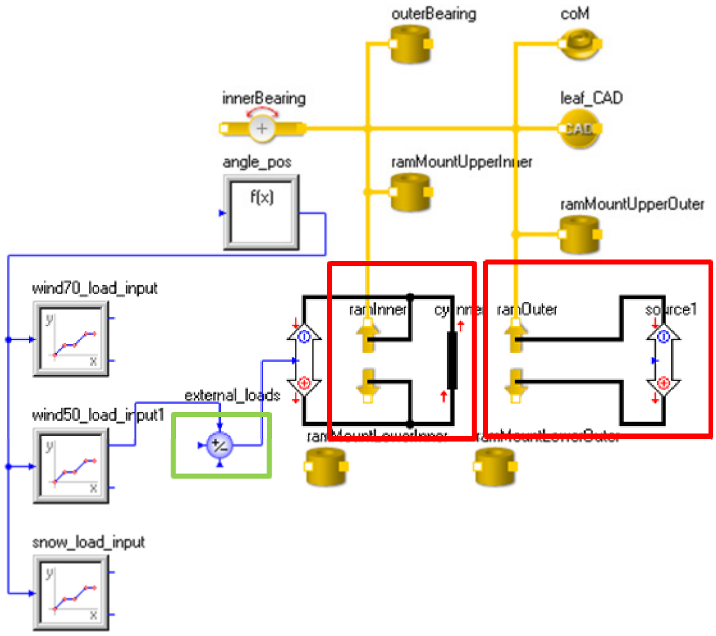

Figure 4: Integration of the complex leaf geometry

With the three separate curve elements and summary element different situations of external loads can be modeled.

2.1.2. Bearing and Friction

The element *innerBearing* is the real rigid bearing model for the whole leaf. No elasticity or asymmetric bearing loads are considered. For stop and start procedures friction behavior of the bearing is important. The friction torque in the bearing depends on the load on the bearing. This value is automatically calculated in this 3D model. The friction torque was considered directly in the bearing model from the normal load *F* and the friction coefficient and the bearing radius.

$$T_{fr} = F \cdot 0{,}2 \cdot 0{,}257m \tag{1}$$

$$F = \sqrt{F_{bear\,x}^2 + F_{bear\,z}^2} \tag{2}$$

2.2. Hydraulic system

The hydraulic system consists of the hydraulic power pack with pumps and directional valve for each cylinder and two cylinders with manifolds with counter balance and safety valves.

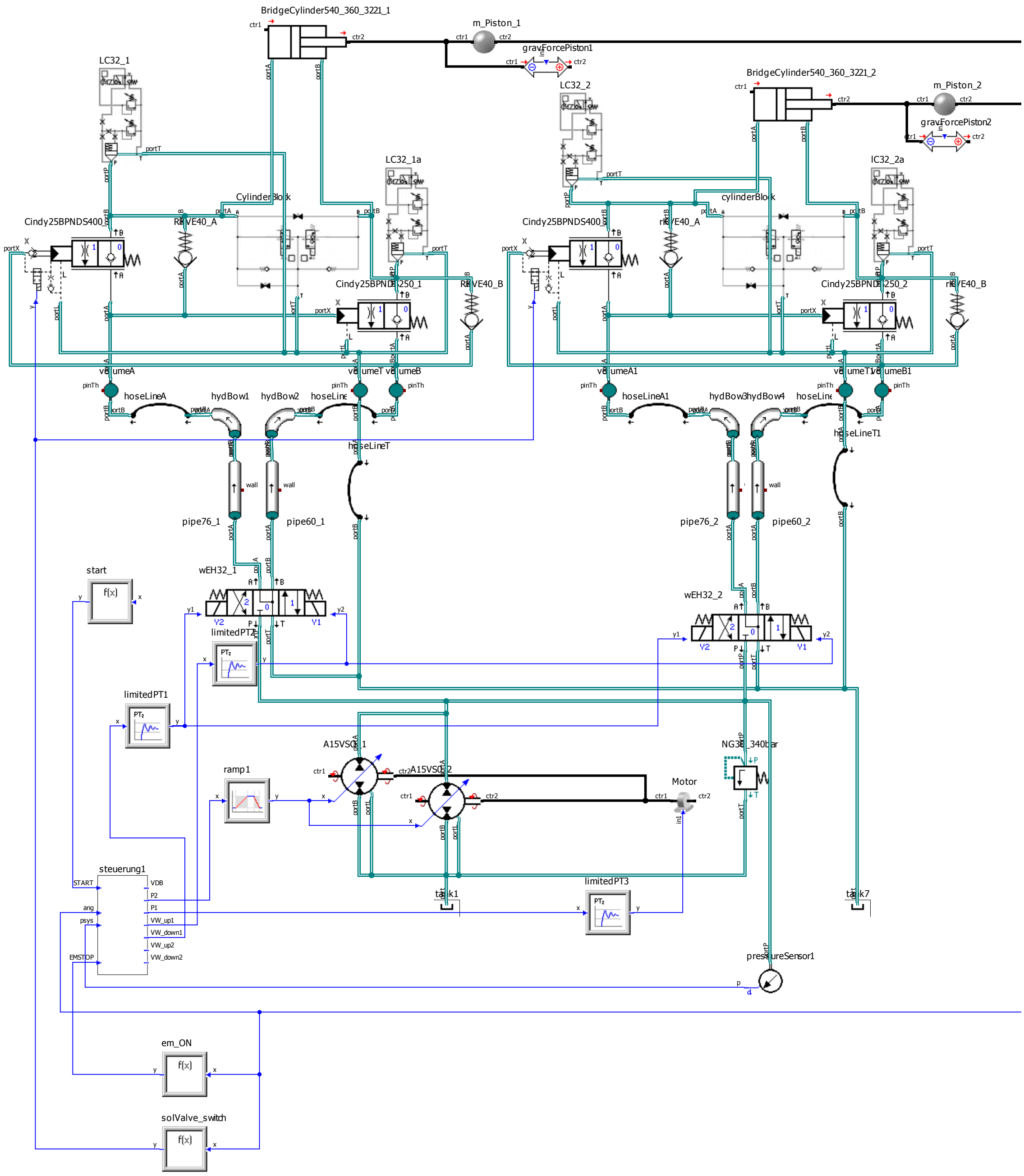

Figure 5: Complete hydraulic system of the main drive for one leaf

The power pack model considers the behavior of the two pumps with adjustable flow and pressure control. Also pressure limitation by a safety valve is included. The directional valve models consider the flow behavior and switching time.

The control block “steuerung1” delivers discrete signals. Behind this block is a state machine described with the internal state chart editor.

The outputs of the control block will be handled in separate blocks for dynamic behavior of the different devices. Pump speed is settled up from beginning. The pumps start to rotate and the displacement is at the minimum value of 5%. After 2 sec the pressure relief valve is actuated. After another second and if the pressure has reached the setting value the directional valves are switched. After that the pumps are activated to increase the displacement volume. In principle different setting values for the pump control are possible. These values can be changed depending on the angle at the bearing.

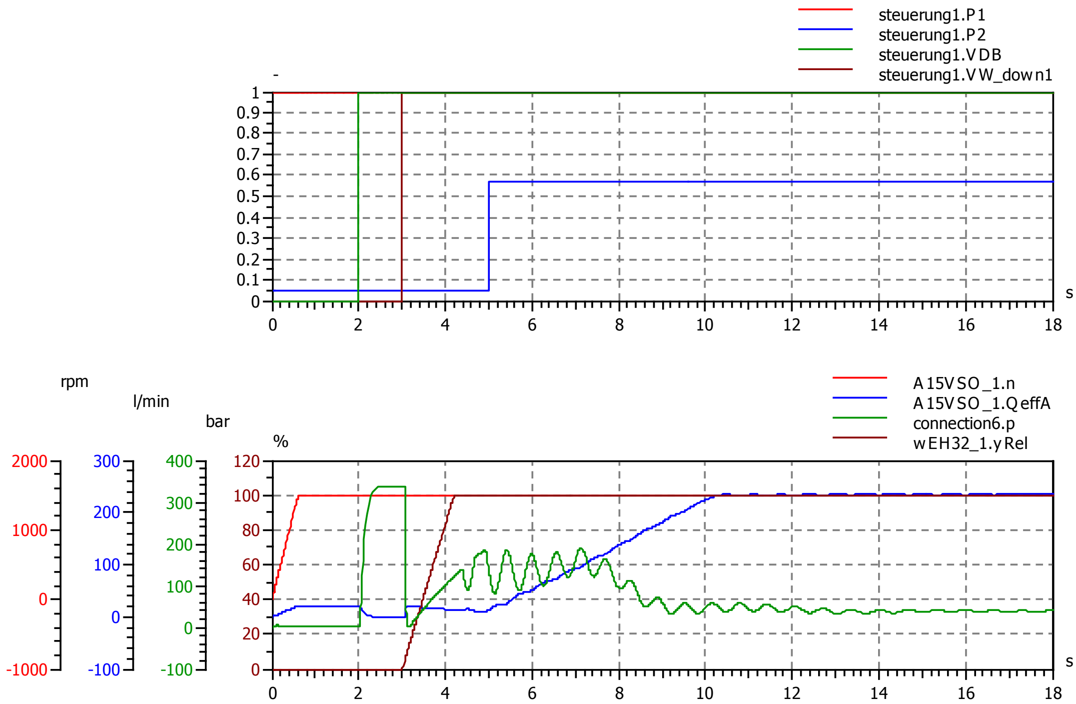

Figure 6: Control module outputs (above) and responses (below) of the pumps and valves (speed – red, displacement – blue, pressure valve – green, directional valve – brown)

Figure 6 shows how the control block controls the devices and also the system response. The lower diagram shows that the pumps start up with low pressure and minimum displacement. If the pumps are running the pressure relief valve will be energized to check the supply of maximum operation pressure. After that the directional valves are switched to the position regarding the direction of operation. The control of the speed is done by the pump displacement control.

The components of the power pack but also the components of the manifold are modeled with standard elements or as user defined and detailed structures.

The model for directional control valve is integrated in the system model like shown in the figure. Each solenoid is energized separately considering dynamic effects. The dynamics blocks *limitedPT1* and *limitedPT2* consider de dynamic behavior of the valves, mainly a slope time for opening and closing. This slope time is adjusted by the installed throttle valves between pilot stage and main stage. The model runs with equal values for both valves. The control signals come from controller as discrete value (0/1). The dynamic behavior of both directional valves is identically.

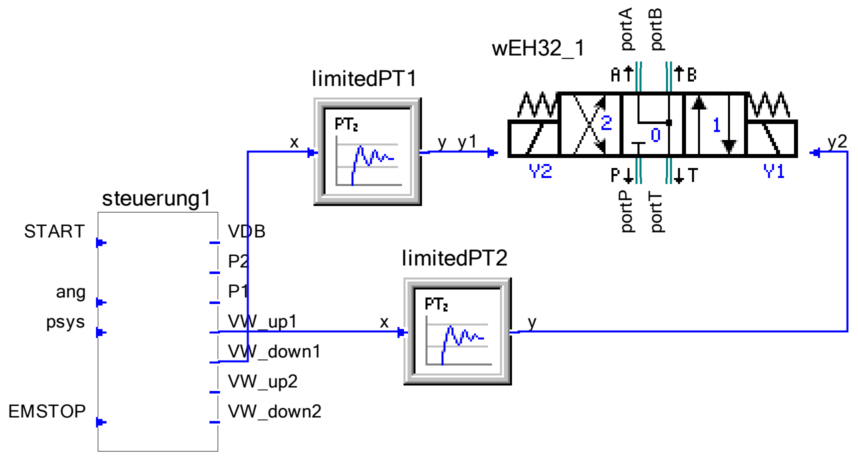

Figure 7: Directional valve model with dynamic blocks, signals come from control center

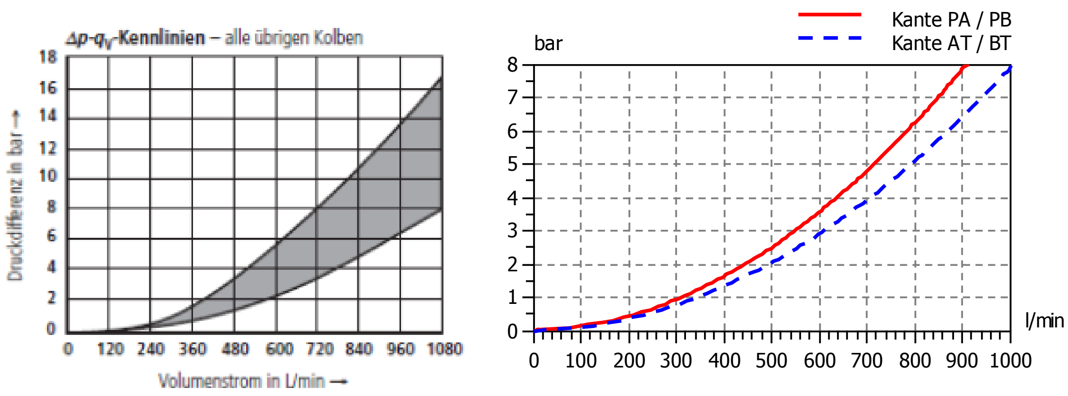

Figure 8: Pressure drop curves of the valve data sheet /2/ and the model

The **Figure 8** shows the flow curves of the valve model. The parameters are adjusted for the lower values in the given range. Edges for the return line (AT, BT) have lower pressure drops.

The opening dynamics is shown in **Figure 9**. The valve contents a nozzle to limit the X port control pressure. Simulation runs have shown the necessity to increase the closing time for better behavior in emergency cases.

The figure shows the discrete signals from the controller, the outputs of the blocks for dynamic behavior and the response of the valve opening signal. The response time of the dynamic blocks is influenced by the throttles mostly.

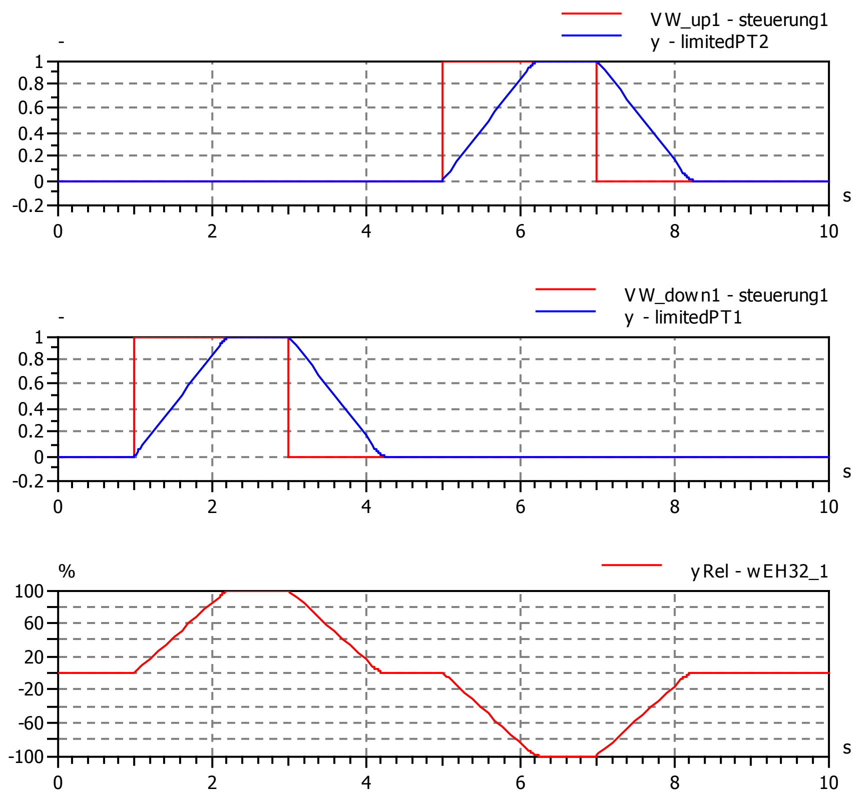

Figure 9: Opening behavior of the NG32 directional valve, response of the dynamic blocks

One challenge is the model of the counter balance valve. It was not sufficient to use a simple element. The valve was modeled in detail with all mechanical subsystem and hydraulic resistance network. The model was validated from measurements and data from manufacturer.

3. Load cases and results

From mechanical and hydraulic part a complete system model was generated. The client has requested to see results for different load cases for each direction of operation and some emergency situations also. In general for evaluation of the system behavior a common set of results was defined (**Figure 10**).

All following diagrams show results from the simulation.

Upper diagram:

- Angle of the pivot bearing (red curve). Zero angle is in closing position. Maximum (88 deg) is in opening position.
- Speed (green curve) and
- stroke (blue curve) of the cylinder

Middle Diagram:

- Cylinder force resulting from hydraulic pressures and piston/rod areas

Lower diagram:

- Cylinder pressure piston side (red) and rod side (blue)

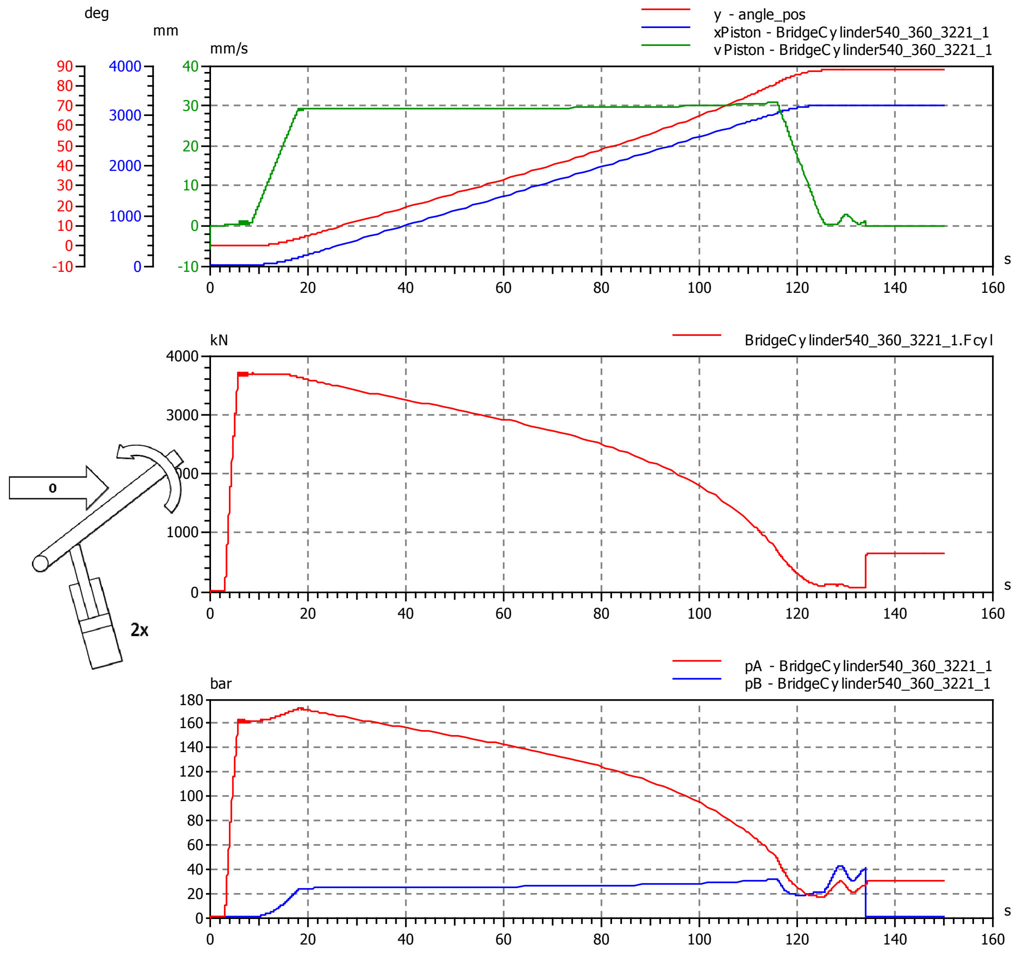

Figure 10: Results for regular load case, opening with two cylinders without any additional load

4. Summary

The behavior of the hydraulic drive of the Poole Bridge was analyzed by means of modeling and dynamic simulation.

The models consider rigid bearings and bodies for the mechanical parts. The hydraulic system model considers all elastic (oil, hose), frictional and dynamic effects of the included components.

It was shown that the drive system works well in different situations also in case of emergency stop.

During the analysis some hints was given for modifications of the system or definition of the control signals from control device.

5. Literature

/1/ N.N Second Opening Bridge – Poole, documentation from Borough of Poole Transportation Services

/2/ Data sheet RD24751/08.08; RD 24 751/02.03, Bosch Rexroth AG