

Fast servo hydraulic actuator: simulation vs. testing

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Kurzfassung

Die Firma Hatebur Umformmaschinen AG mit dem Hauptsitz in Reinach, Schweiz entwickelt und vermarktet hochwertige Umformmaschinen und Werkzeuge, mit denen sich Präzisionsteile aus Metall in großen Stückzahlen im zweistelligen Millionenbereich im Jahr herstellen lassen. Das Familienunternehmen Hatebur hat nach seiner Gründung 1930 eine Reihe bahnbrechender Produkte entwickelt und einige Meilensteine in der Geschichte der modernen Massivumformung gesetzt.

Mit den vollautomatischen Kalt- und Warmpressen wird ein weites Spektrum von Teilen hergestellt, die hauptsächlich ihre Anwendung in der Automobil-, Wälzlager- und in der Befestigungsmittelbranche finden. Die Desmodromik, die mechanische Zwangssteuerung der Maschinen trägt wesentlich zur Zuverlässigkeit, zur Bewegungspräzision und bei entsprechender Wartung zur Langlebigkeit der Pressen bei. Als Beispiel sei hier die erste AMP 70 genannt, die 1964 als größte horizontale Warmpresse ihrer Zeit auf den Markt kam und bis heute in Betrieb ist.

Ein weiterer Vorteil der mechanischen Zwangssteuerung spiegelt sich in der kompakten Bauweise der Maschinen wieder. Diese erweist sich aber zugleich als Nachteil, wenn neue Funktionen im begrenzten Montageraum eingebaut und getestet werden müssen.

Für die Erprobung zwei neuer Maschinenfunktionen unter Produktionsbedingungen wurden aufgrund der hohen Dynamik und der Leistungsdichte servohydraulische Achsen gewählt. Bei der Anwendung handelt es sich um einen extrem schnellen Antrieb, der an seinen dynamischen Grenzen betrieben wird, das heißt: die benötigten Geschwindigkeitsänderungen finden im Bereich der Antriebs-Zeitkonstante statt. Die Regelstrecke als Schlüsselbestandteil des Regelkreises wurde mit größter Sorgfalt in der Simulation abgebildet. Eine wesentliche Voraussetzung für jede Simulation sind professionell entwickelte Modelle der beteiligten Komponenten.

Der erste und praktisch erprobte Einsatz von SimulationX im Hause Hatebur hat gezeigt, dass das Verhalten dieser servohydraulischen Achse mit einem sehr hohen Realitätsgehalt nachgebildet werden konnte.

Abstract

Hatebur Metalforming Ltd. with its headquarters in Reinach, Switzerland, develops and puts on the market high-quality forming machines and tools, which are used to manufacture precision metal parts in large quantities - tens of millions per year. After

its foundation in 1930, the family-owned company has set some milestones in the history of modern bulk forming and the development of groundbreaking products. The full automatic cold and hot forming presses produce a wide range of parts, which are basically needed in the automotive, bearing and in the fastener industry.

The desmodromic design contributes significantly to the reliability, the movement precision, and with appropriate maintenance, also to the longevity of the presses. For instance, the first AMP 70 built in 1964 as the largest horizontal hot forming press at that time is today, after more than 50 years, still in service. Another advantage of the desmodromic control is the compact design of the machines.

However, at the same time, this also proves to be a challenge especially for designing and testing new features in a limited installation space. Due to the high dynamics and power density a servo-hydraulic axis was chosen to develop and test a new machine function under production conditions. The application consists of an extreme fast axis, which operates at dynamic limits, that is, the required velocity changes take place in the range of the resonance frequency. The closed loop control structure was mapped in SimulationX with the utmost care. Essential preconditions for any successful simulation are professionally designed models of the all related components.

The first and practically tested use of SimulationX at Hatebur shows, that the behavior of the servo-hydraulic axis can be simulated with very high reality content.

Main Part

In the horizontal forging machines a hot rod with a temperature of approximately 1250°C is drawn by the feed rollers against a fixed bar stop. Subsequently, the bar is mechanically sheared in machine tact and the cut-off is transported either by the shear head or by the grippers in front of the first forming station. The position of the bar stop head has to be also adjustable in order to ensure the proper cut-off volume for the forging process. The cut-off length adjustment is usually realized by a servo mechanical actuator.

The cut-off quality is decisive for the subsequent forming processes. Every little improvement brought to the shearing process has a large influence over time due to the mass production of millions of parts per year. Nowadays there are some forged parts with specific sections that do not require further mechanical machining after cold forming.

Among other issues concerning the cut-off quality the question raises up, if the rectangularity of the cut-off can be improved by designing the bar stop in a way that ensures the following of the shear head during the shearing process and thus also results in eliminating the friction between the hot part and the bar stop.

Due to the very limited installation space, cost reasons and easy-to-adjust capability, it was decided to design the follower bar stop device and other functions as servo hydraulic axes:

- One axis for adjusting the cut-off length referred as the X-axis and

- One axis as follow-up function of the shear head, referred as the Y-axis. The Y-axis has to retract as fast as possible, before the shear head reaches its maximum extracted-position in order to avoid a collision with the grippers installed on the transfer system.

Both axes were designed for use in a middle sized hot forming press called AMP 30, which is capable to form parts up to 0.7 kg at a rate of 140 parts per minute.

For the designing process and the experiment itself the rate was set to 120 strokes per minute.

Figure 1 presents the situation with the highest dynamic because the Y-axis starts delayed when the shear head has passed a certain idle stroke of 5 mm, given by the design of the shearing blade.

The Y-axis accelerates during a displacement of 3 mm catching up the position of the shear head.

Shearing a bar of $\varnothing 32$ mm at a stroke rate of 120 parts per minute takes about 25 milliseconds with an open-shaped shear blade, as it is shown in Fig. 1.

To minimize the friction between the hot bar and the bar stop, the two movements, the shear head and of the Y-axis, have to be nearly synchronous during this short time.

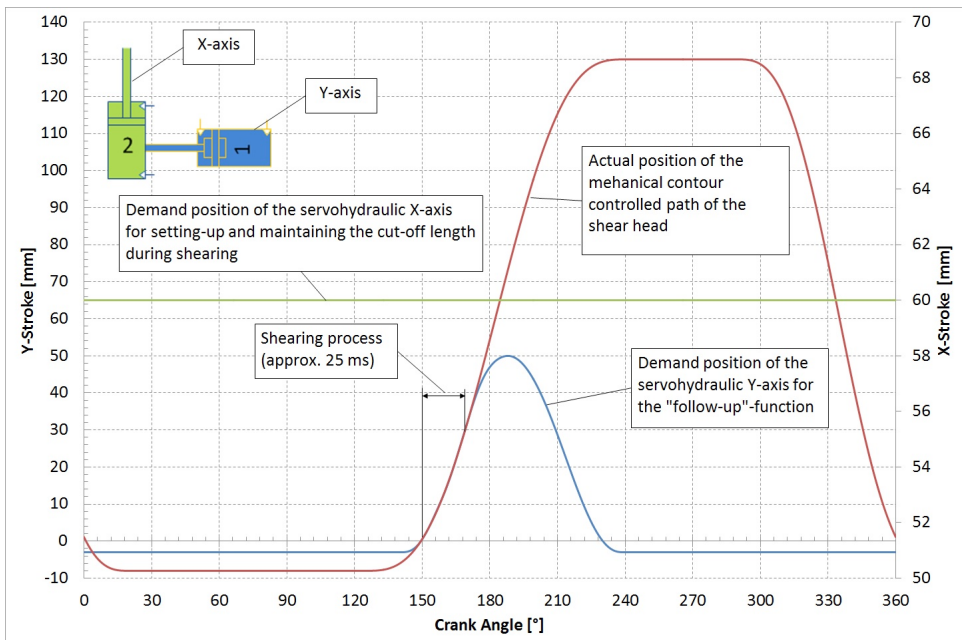


Figure 1: Displacement vs. time function.

The challenge was to design the servo-hydraulics in a manner that enables it to handle a position-control-error to the desmodromic motion of the machine smaller than ± 0.25 mm with following general conditions:

- Moving mass: 70 kg;
- Maximum extracting and retracting time of the Y-axis: 0.15 s;
- Stroke: 45 mm.

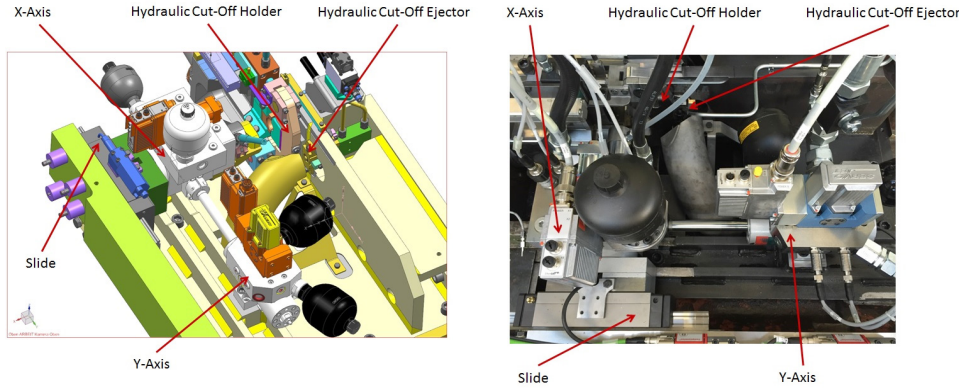


Figure 2: Test assembly; a 3D-CAD-representation (left picture); b real hardware (right picture).

Based on a first analytical approach of the nominal flow rate of the servo valve and the cylinder dimensions, the simulation model was built-up by setting the parameters for the following components:

- Cylinder: Hänchen $\varnothing 40/\varnothing 25/75$ mm with integrated position sensor based on the magnetostrictive principle and EtherCAT interface;
- Servo valve: Moog-D671 with ServoJet® High Flow Pilot Stage and customized spool design.

The tool area of the hot forming press had to be completely redesigned for the experimental tests. Among the two new servo-hydraulic axes X and Y there had to be found a solution for replacing the mechanically actuated cut-off holder and also for developing a device for ejecting the cut-off from the shearing blade into the waste pipe. Both of them were also realized as hydraulic actuators. By mounting the new appliance on a separate plate, it was possible to commission the complete system without a real machine avoiding costs taking the press out of production.

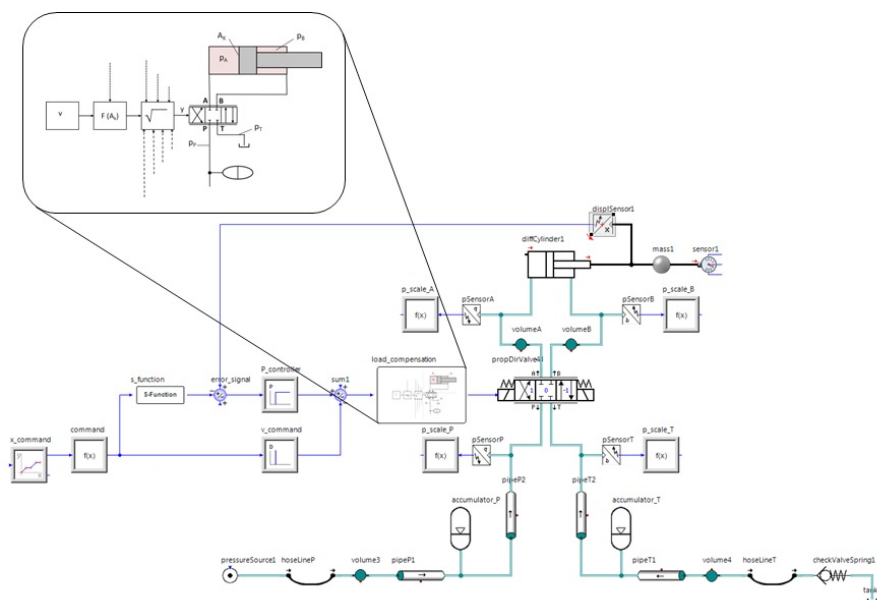


Figure 3: Simulation model.

The control structure is in the first step a typical closed loop position control ("P_controller"-block). An additionally feed forward function ("v_command"-block) is added to meet the requirements of the high dynamic behavior. The feed forward function computes a signal as a derivative of the position demand signal and is added by ("sum1"-block) to the control signal of the "P_controller". The new control signal passes a special function ("load_compensation"-block). This block improves significantly the robustness of the system by computing a load-independent valve demand signal comparable with the function of the subordinate velocity control circuit as it is used in control structures of the electromechanical applications. Out of this reasons this block is further named as "load compensation module". Unfortunately, during commissioning it was noticed that in the mounting plate of the servo valve the two cylinder ports were inverted, i.e. the A-port of the servo valve leads to the B-port of the cylinder and vice versa. This should never be done in combination using a servo valve having a customized spool design for reasons which will be later detailed. In spite of the enabled load compensation module, the position controller was not able to reach the specifications shown in Fig. 4 a. This unexpected situation was taken as an opportunity for further testing the capability of SimulationX in modeling the high dynamic behavior of a servo hydraulic actuator.

Figure a

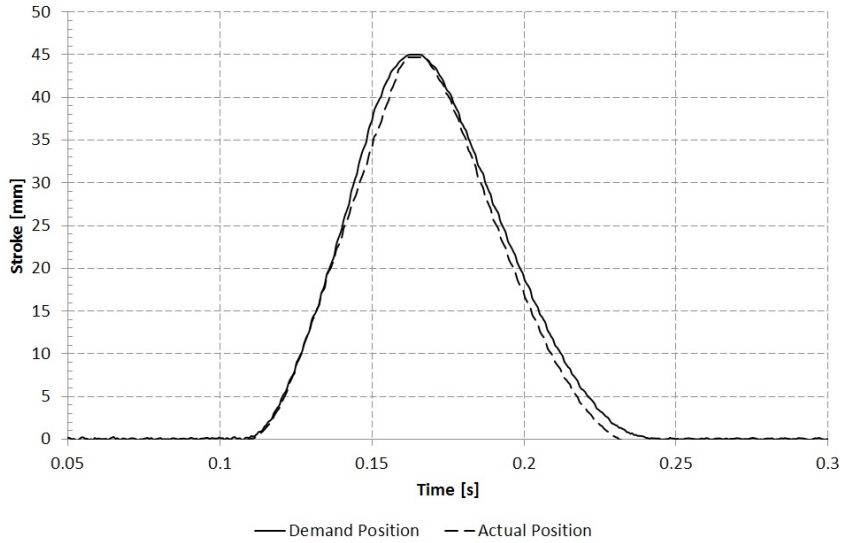


Figure b

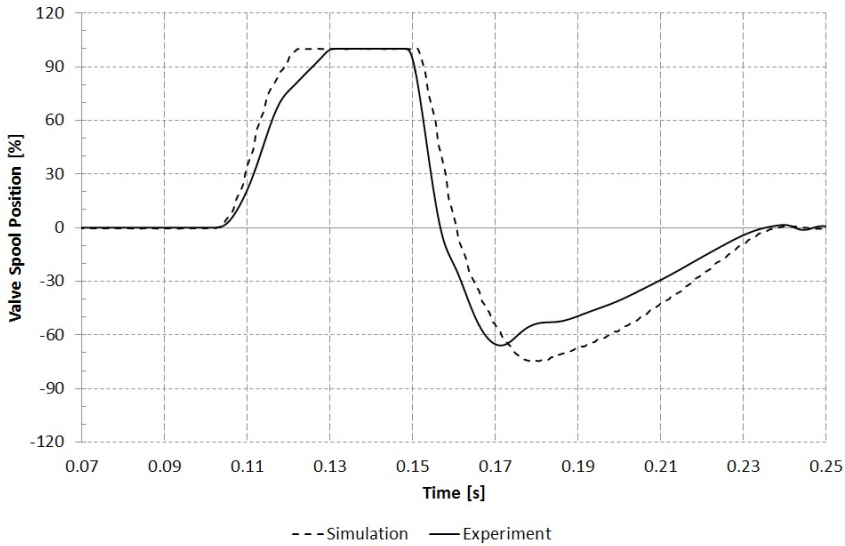


Figure 4: Actual value vs. position setpoint with inverted connecting ports of the mounting plate and simulated valve opening p vs. commissioning records.

The actual spool position of the servo valve, the valve opening, is very well precalculated by simulation (Figure 4 b). This phenomenon is clearly shown by the simulation as by the experimental records as well (see Figure 5 a-1 and 5 b-1).

Figure a-1

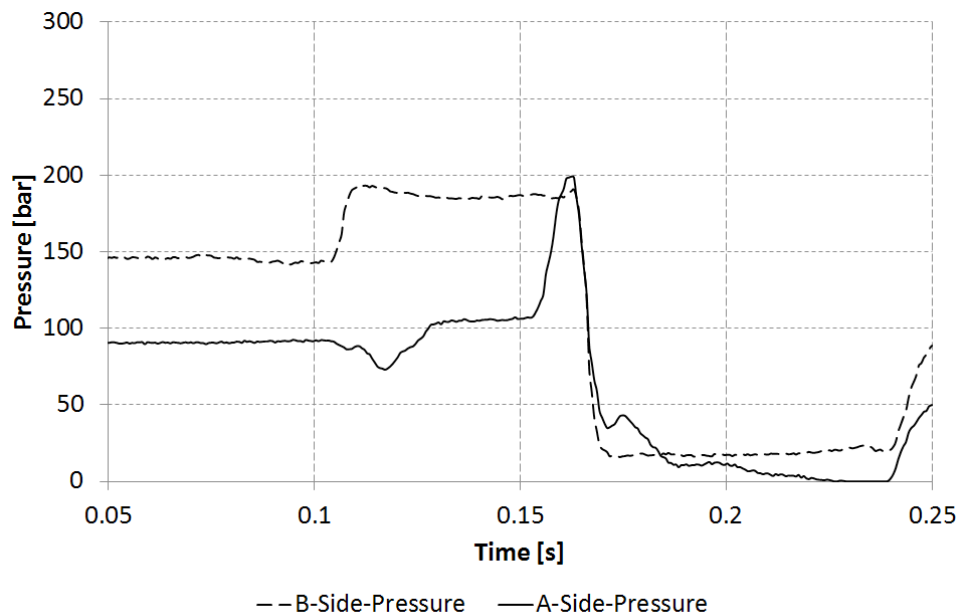
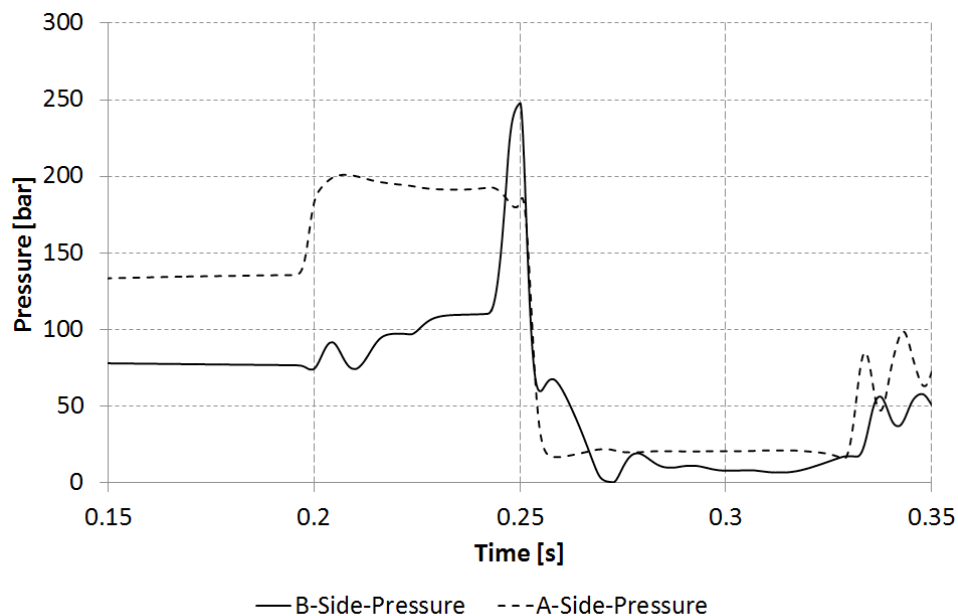


Figure b-1



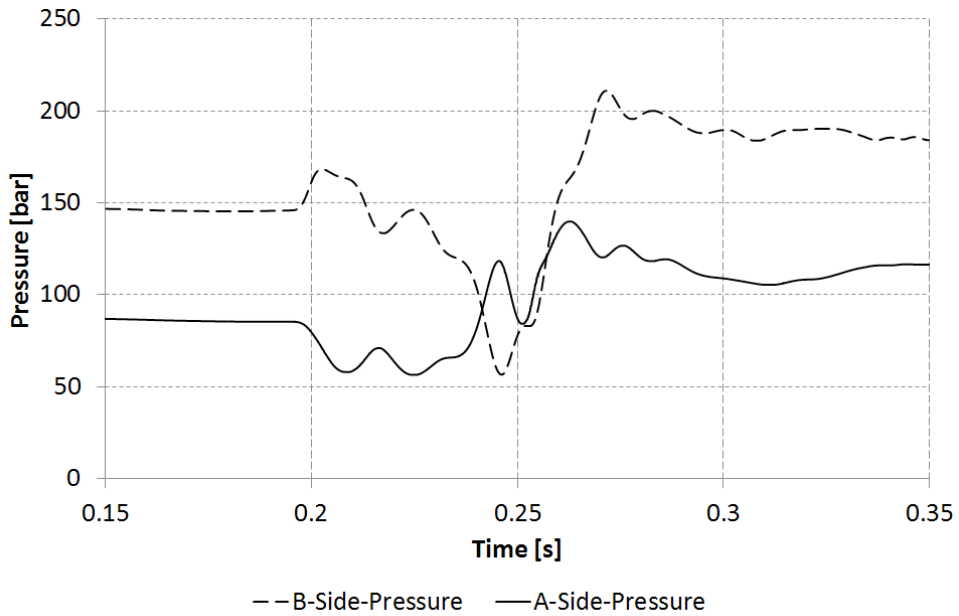


Figure b-2

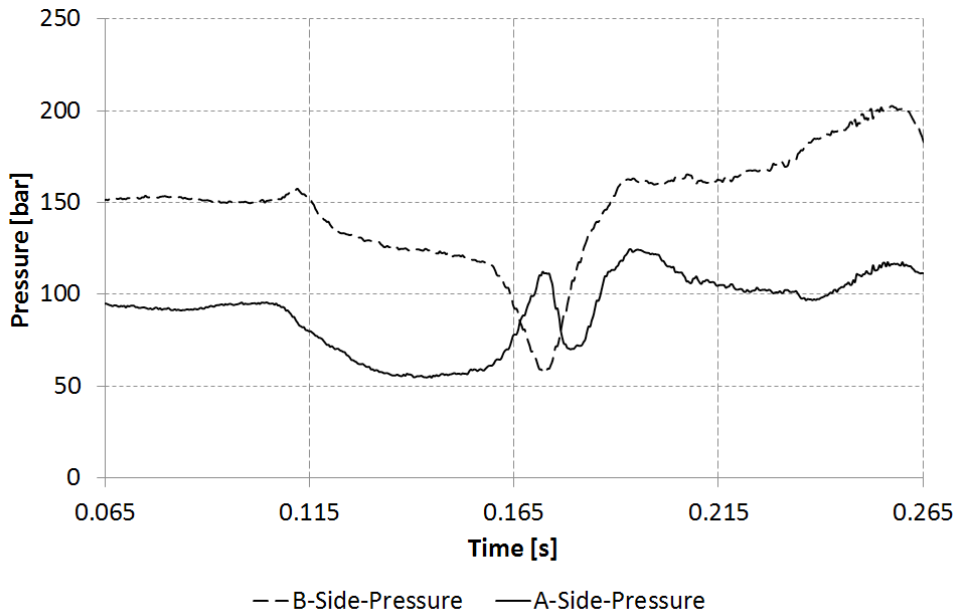


Figure 5: 1 - mounting plate with inverted cylinder ports, 2 - mounting plate suited for the customized valve edges. a-1, a-2 - simulation, b-1, b-2 - field testing result.

A cavitating hydraulic system cannot be controlled. Among other problems coming out of cavitation, there rises the risk of damaging all seals of cylinder, servo valve and mounting plate. Even at the spool of the servo valve can occur material erosion. Another effect of the inverted ports of the mounting plate feeds the servo valve into saturation (Fig. 4 b) which reduces the dynamic reserve absolutely to zero. This is a very good example to emphasize the fact that the physical limits of a drive cannot be exceeded even with the best possible controller. After installing a new mounting plate with correct layout of ports the system operates under normal conditions with no more cavitation or saturation effects. During the shearing process a position control error of ± 0.15 mm was reached. This result is within the requested tolerance of ± 0.25 mm (Fig. 6 a). The position control error is larger at the reversal point and there is a small discrepancy to the simulation results. This deviation does not affect the shearing process. In fact the Y-axis follows the mechanical displacement of the shear head and has benefits for the process. Fig. 6 b shows the dependency of the controlled accuracy of the cycle time of the controller.

As shown by the experimental results, it is not allowed set cycle times slower than 50 μ s. The advantage of using the load compensation module (Fig. 6 c-d) can be observed in the simulation and in performing the experimental tests as well. The load compensation module has a major influence to the performance of the servo hydraulic system while performing on the real equipment in the machine.

Figure a

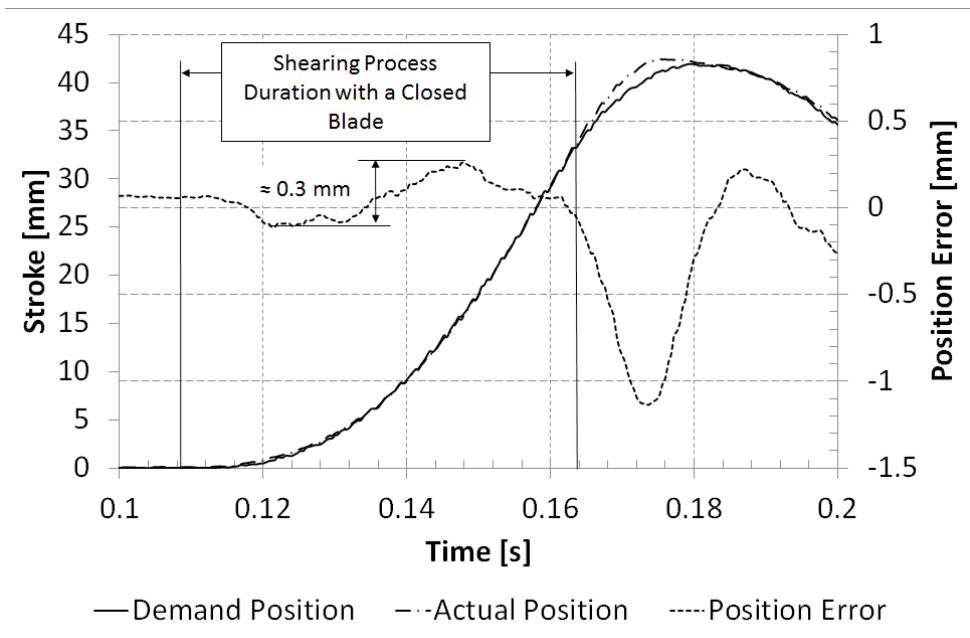


Figure b

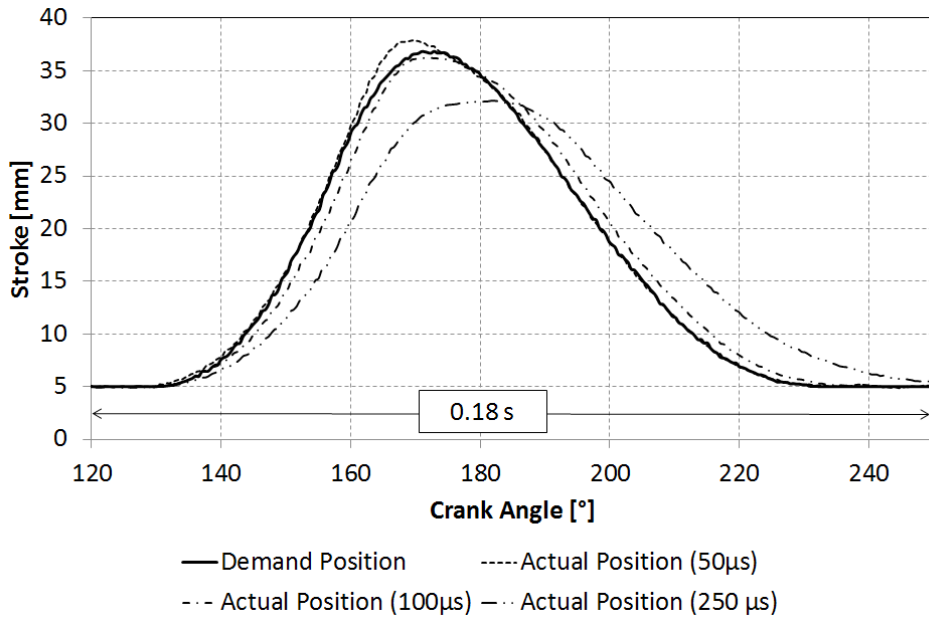


Figure c

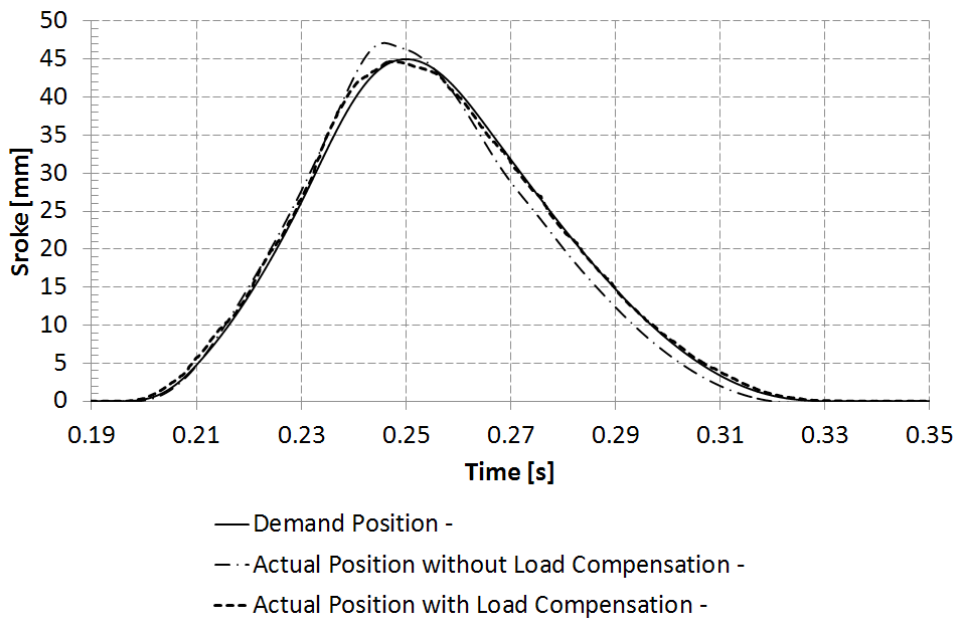


Figure d

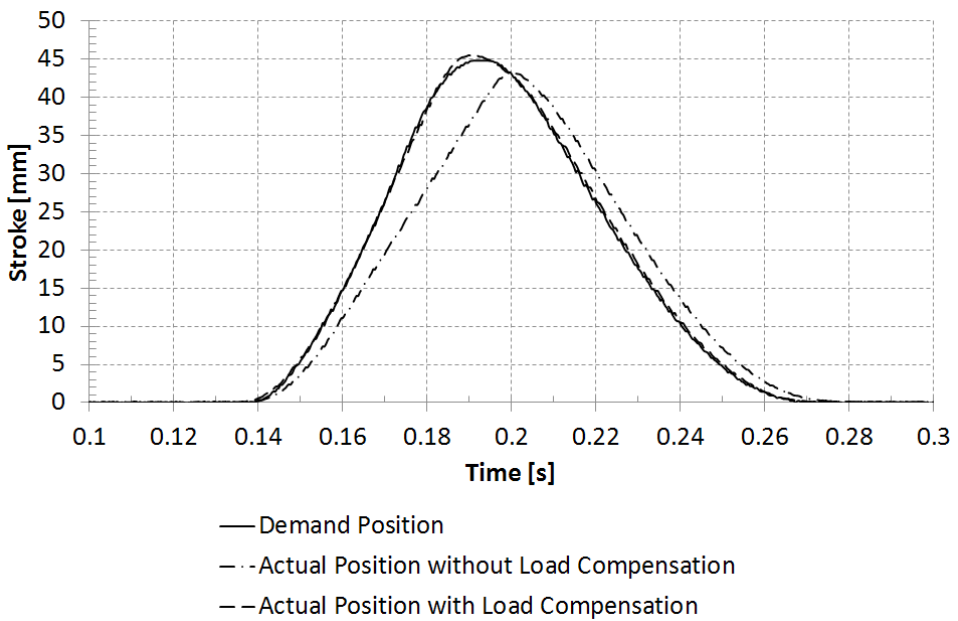


Fig. 6: a – Position error over time during shearing at 120 strokes/min; b – influence of the controller cycle time on the actual position; Stroke over time: c - simulation, d - field testing result.

This declares clearly why it is designed to compensate external influences affected by forces, by friction, by drift and by the product itself which are continuously changing and thus very difficult to be quantified in the simulation model. The records at Fig. 6 d show clearly that the load compensation module reduces massively the contouring error; the actual position value is all the time very close to the position demand signal.

Summary

A new machine function of a desmodromic driven forging machine had to be tested. Due to limited installation space, cost and time development reasons and last but not least because of the high dynamics and forces and easy-to-adjust capability, two servo hydraulic axes were chosen to meet the specifications.

During production the boundary conditions like load and friction change continuously. These parameters are very difficult, nearly impossible to implement in a simulation model. That is why the load compensation module does not necessarily lead to major performance improvements in the simulation results of the servo hydraulic actuator. This module reveals its real capabilities during production conditions in the real machine because the valve demand signal is automatically readjusted in order to maintain the rated flow demand calculated by the controller structure. The task of showing the proximity of the simulation results to reality, if the simulation set-up is build up with utmost care and considering all known parameters of the controlled system has been

achieved. The trial-and-error-method is not an option to be considered in hydraulics. SimulationX has successfully proven to be a reliable tool for modelling high-dynamic servo hydraulic actuators and gives a guarantee for the success of further similar projects at Hatebur.