The speed up of vibrating hydraulic jaws by smart control of electric solenoids

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***Abstract* – Advanced Electro-Hydraulic Systems (AEHS) are the only way to achieve top-notch parameters for high-end vibration machines. The AEHS is intended to a more complex forming test system developed at University of West Bohemia. The AEHS speeds up the hydraulic by increasing pressure in the plunger box by pistons driven by solenoids with proper timing. The development and testing of the AEHS device are described in the paper.**

Keywords – Hydraulic physics; High Power solenoids; Hydraulic speed up; Solenoid driver; Steel instrumentation; PWM;

I. Introduction

The General-Purpose Forming Demonstrator (GPFD) tests is developed in a frame of project CZ.01.1.02/0.0/0.0/19_262/0020258 at department of Electronics and Informatics. [1] [2] [5]

The GPFD consist of several parts:

- Hydraulic system – oil handling part
- Heating system – power part
- Cooling system – power part
- Control system – industrial PC, sensors and actuators

The demand for vibrations of tested sample by hydraulic system is as follows:

- Higher limit of vibration frequency is 50 Hz
- Slope of hydraulic plunger move up to 2 ms
- Magnitude of vibration is up to 15 mm
- Force limit is 300 MPa

The hydraulic system has no problems with last two demands. The first two are too tough even for fast oil valves. The biggest delay is at the beginning of opening the valves. Thus, the additional increase of pressure in the hydraulic box of the plunger several hundred microseconds before the move the valve helps the plunger to achieve higher slope of movement. The idea was realized and is described below.

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II. Device Architecture

Design should satisfy these specifications:

- Controllable delay of the pulse beginning
- Settable solenoid energy by PWM
- Solenoid turn-on current up to 30 A, hold current approx. 5 A (adjustable by PWM)

The one-half of AEHS architecture is shown in Fig. 1. Four solenoids are used for one direction of movement and another set of four solenoids for movement in an opposite direction. Both halves are identical. All channels are the same. Each channel of the AEHS consists of two blocks:

- Control Board
- Solenoid with temperature sensor.

The Control board circuits should fulfill three points mentioned above. The STM32G061K6T6 controller was used to generate PWM, measure current by HAL sensor, measure position of plunger by linear potentiometer and measure solenoid temperature. The Control Board is described in detail in chapter III Hardware.

The AEHS is controlled via Industrial PC by digital inputs Startx and it sends Errorx messages.

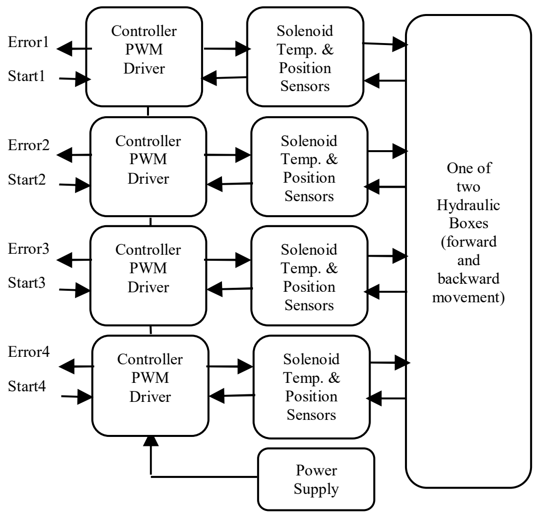

Figure 1. One half (four channels) of AEHS block diagram

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III. Hardware Description

The **solenoid** type 874F from Geeplus company was chosen due to its ability to withstand the large overcurrent and increase the mechanic forces [3] [4]. It drives four piston diameter 6 mm and stroke 2 mm for one direction. Even of that solenoid, the power delivered to the winding with given limits of voltage and current necessary to keep, did not meet the timing of mechanical characteristics we required. The inductance has to be decreased to meet speed requirements. We decreased the number of turns to match the slope of mechanical movement to the level two milliseconds. Once the solenoid was disassembled, the temperature sensor was incorporated into windings. Final solenoid parameters are as follows: 13,4 mH, 1,2 Ω, 315 turns.

The **control board** consists of controller STM32G061K6T6, HAL current sensor, integrated MOSFET Driver 1ED020I12-F2, with desaturation protection, and SiC MOSFET. For faster solenoid turn-off the power resistor is connected to the turn-off solenoid circuit. During the solenoid turn-off, energy accumulated in solenoid magnetic circuit is wasted in the power resistor. Thus a rapid current drop is achieves even though the solenoid inductance is relatively high. The supply voltage of power stage can rise up to 100 V. The solenoid switch on current is around 30 A per one solenoid channel. The solenoid overvoltage during the switch off is about 1,2 kV.

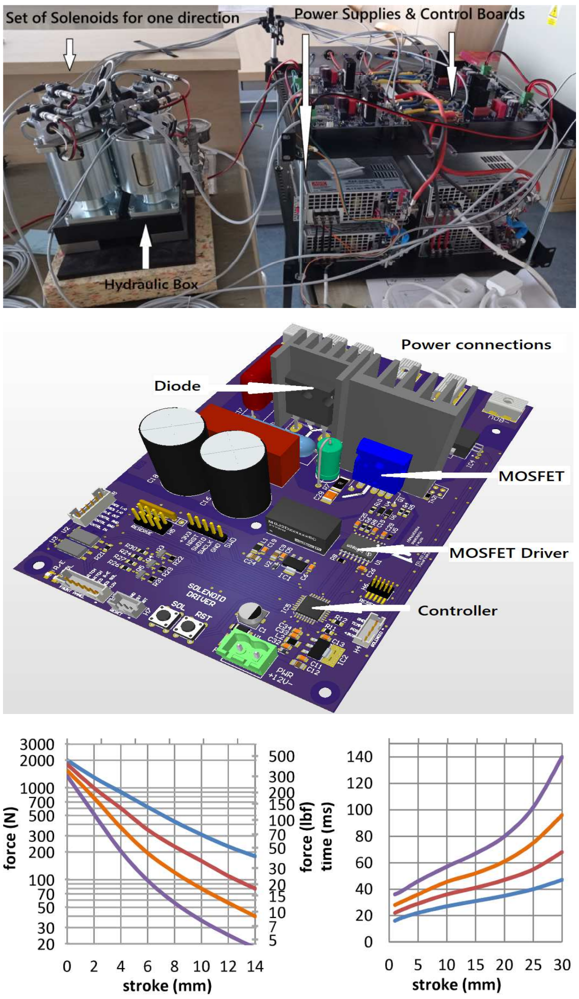

Figure 2. Hardware, AEHS ass., Control Board and solenoid chars.

Fig. 3 shows the driver circuit diagram.

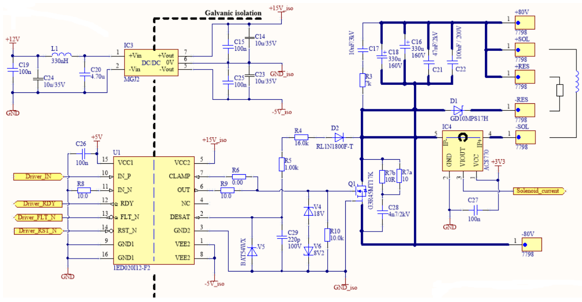

Figure 3. Driver circuitry

After the successful test of the control board prototype a new PCB integrating the driver and microcontroller into one board the one direction of the AEHS can be designed with respecting the required rack form factor.

IV. The Software Description

The AEHS software was developed according to the previously mentioned requirements. Whole project was developed using STMCUBE v12.3 from STMicroelectronics.[7]. It was chosen due to the used Microcontroller STM32G061K6T6. Source code is fully written in C language. Flow chart of the software is shown on Figure 4.

The flow diagram depicted in Fig. 4 is described in a detail in the following paragraphs.

1. ***Controller Initialization***
   The Controller initialization consists of initialization of all internal and external peripherals. The internal peripherals used are Timer/Counter, GPIO, and Interrupt Controller. The MOSFET Driver is external peripheral only and it has to be reset before the operation.

2. ***Read Driver Status***
   The MOSFET Driver from Infineon is a smart device. It has three communication signals: input Reset and outputs Fault and Ready. The Ready and Fault are periodically read during the Main Loop. The MOSFET Driver failure is one of hard errors. The controller stops the solenoid activity when failure occurs.

3. ***Read Temperature, Current, Position***
   Two values read after Driver Status are hard. These values are Position and Temperature. The last one Current value from HAL sensor is soft error when no current state and the solenoid is off anyway. The former two ends in endless hard Error Loop state. The zero Current error does not force the software into the Error Loop state.

4. ***Start signal, Switch on and off Solenoid Interrupt***
   The Start signal from Master Industrial PC is fed into the GPIO input programmed as alternative interrupt input. The interrupt sensitivity is toggling to rising and falling edge according to previous value. The

opposite is set for the switching Solenoid current on and off by MOSFET.

5. ***Error Loop***
The Error Loop is the endless loop where the hard errors end up. If the loop is entered, the code of error is outputted as sequence of logic values on Error outputs of the control board.

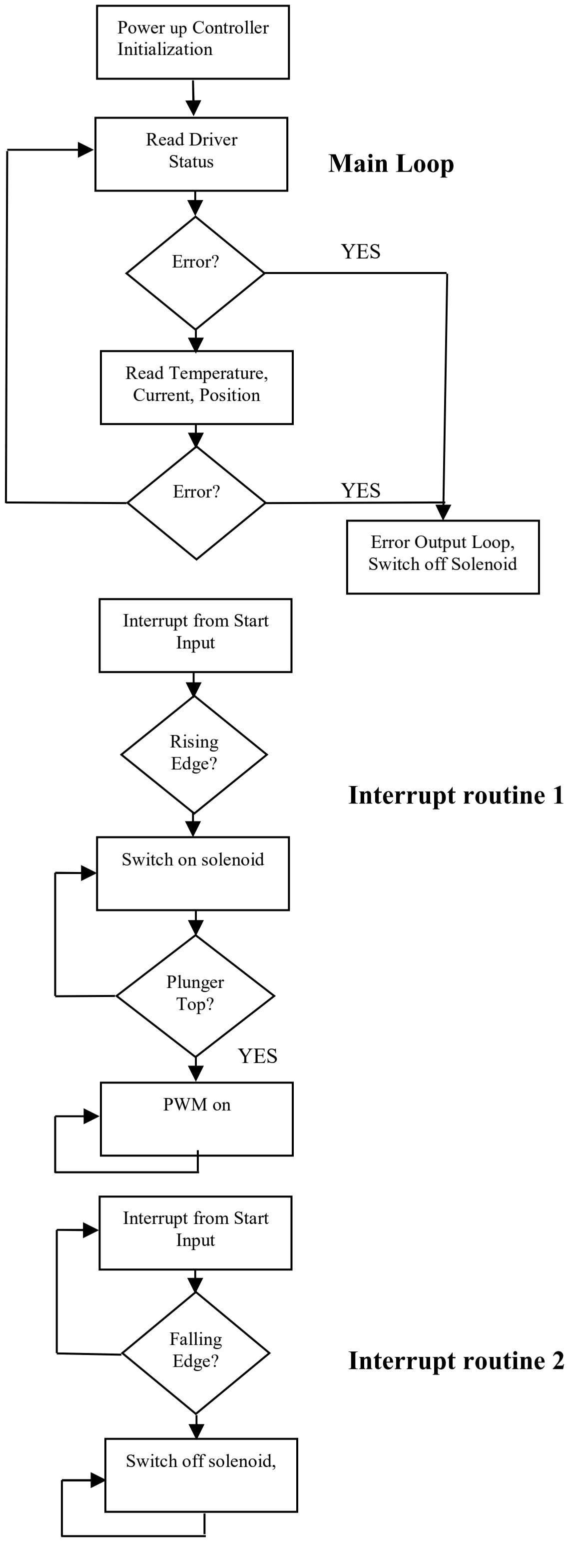

Figure 2 Flow chart of software

V. ADDED SAFETY MEASURES

Even during the test, it is important to have all of the relevant information about the AEHS. The Master device (Industrial PC) does that by monitoring of the values of Error outputs. These outputs indicate any error raised on the solenoids or electronics. The information can be used for diagnostic purposes when error occurs.

During the testing period, it is possible to access the device error messages any time. For this reason, safety measures were implemented. The Controller monitors several values and performs tests for limits:

- solenoid temperature
- position of the solenoid plunger
- solenoid current
- self test of the board and its environment

The controller communicates with industrial PC by the control lines Startx inputs and Errorx outputs. The errors are evaluated in the Main Loop in controller and notify errors on dedicated binary outputs by sequences of logic values.

VI. TESTS AND MEASUREMENTS

The test procedure, which assures the reliability of the AEHS was performed. The several hundred switching cycles with no errors were done by repeatedly writing Start signal to logic one and zero and reading Error status. The Controller also do statistics about errors.

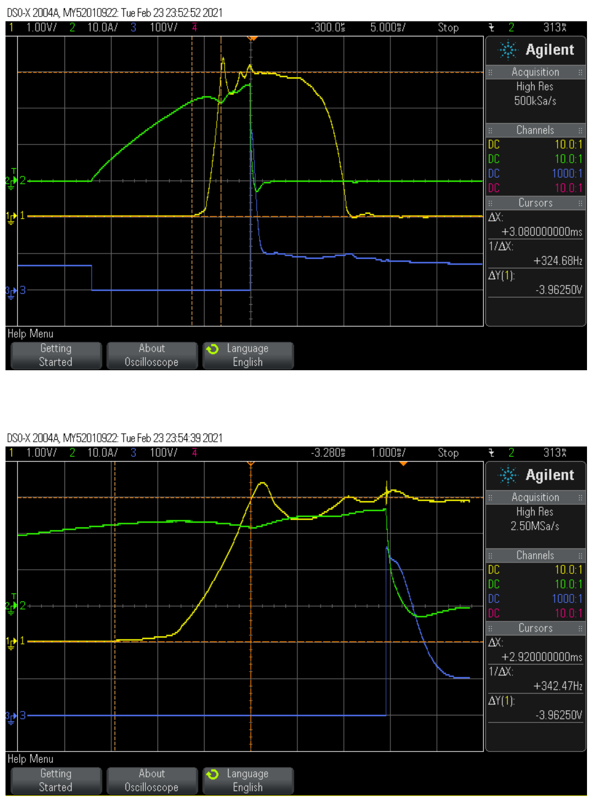

Figure 5. Oscilloscope screen shots of Solenoid switching cycles

The screen shots in Fig. 5 represent turn-on process and plunger movement. Yellow waveform is plunger position; green waveform is solenoid current, blue waveform is voltage across switching SiC MOSFET transistor. The lower screen shot is zoomed detail of upper one and shows the plunger movement during turn-on.

VII. Conclusion

During the test procedures, the AEHS pass all tests within the tolerance bands of error conditions monitored by controller.

The tests were carried out at the test stand shown on Figure 2 with settable pressure under solenoid plungers. The tests of solenoid and control electronics were carried out with pressure 170 Bar. The time of the solenoid plunger movement is lower then 2 ms. The solenoid peak turn-on current is about 30 A. After turn-on the solenoid current is immediately decreased to a holding value. To keep the plunger position the PWM modulation is applied and solenoid current is hold at value approximately 5 A. This current is sufficient to maintain the plunger position.

All projected parameters were achieved.

As the prototype version of the AEHS was tested successfully, a new fully populated version of the AEHS will be placed into rack and then tested in the full assembly of complete General Purpose Forming Demonstrator (GPDF).

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The close cooperation with ATEGA s.r.o., that is responsible for whole project with ID number CZ.01.1.02/0.0/0.0/19_262/0020258, was highly appreciated. We also acknowledge project SGS-2021-005.

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