Purpose

The aim of these series of reports is to give an update of the AAU Testbench concerning its performance and reliability. The overall goal is to mature the digital hydraulic PTO such that it can be implemented in the next generation of Wavestar's WEC. A status of the Testbench is given together with a list of recommended topics to further improve the performance and reliability.

Executive summary

- The power matrix with Bucher valves (chamber V02 with 3x10 valves, chamber V01 and V03 with Parker valves) was measured the 13th of January 2015 and compared against the power matrix with Parker valves only (3 Parker valves for each chamber). The results show that Bucher valves do perform better for all sea states.
- The weighted efficiency(*) of the manifold with Parker valves is 57%.
- The weighted efficiency(*) of the manifold with Bucher+Parker valves is 79%.

(*) The weighted efficiency is referred to as the average efficiency where the efficiency in each seastate is weighted with the probability of the seastate in question. The seastate probabilities are included in the Appendix (see Table A.2 in page 4).

Contents

Power matrix measurements with Bucher and Parker valves: 180[Bar]

A power matrix measurement was performed with Bucher and Parker valves. The efficiencies are displayed in Table 1, the average input power to the manifold in Table 2 and the average output power of the manifold in Table 3. All the cells in each table are divided in two. The results of Bucher at the left and the results of Parker at the right. Note that the Bucher valves are only installed in Chamber 2 (V2l, V2m, V2h) and therefore it is reasonable to expect even better results when the remaining two chambers (1 and 3) are upgraded with Bucher valves.

As can be observed, Bucher valves yield a higher efficiency than Parker across the entire range of wave heights and wave periods. With Parker valves only, the manifold efficiency is equal or above 80% for wave heights starting at 2.25[m]. On the other hand, with Bucher valves the efficiency is equal or above 80% for wave height starting already at 1.25[m]. It is worth to remark that the input power for both power matrixes (see Table 2) are similar, serving as a confirmation that the Bucher and Parker experiments were performed under equal conditions.

		Tm[s]					
		3.5		**4.5**		**5.5**	
Hm0[m]	**0.25**	0	<0	18	<0		
	0.75	71	28	72	33		
	1.25	80	60	80	66		
	1.75			84	79	87	79
	2.25			86	82	88	83
	2.75					89	85

Table 1: *Efficiency [%] of the tested combinations in the power matrix. Efficiency values above 80% displayed with green color.*

		Tm[s]					
		3.5		**4.5**		**5.5**	
Hm0[m]	**0.25**	0.4	0.4	0.6	0.6		
	0.75	3.1	3.0	4.4	4.4		
	1.25	8.2	8.1	11.6	11.4		
	1.75			20.8	20.4	18.5	18.7
	2.25			30.8	30.4	29.6	29.0
	2.75					38.7	38.4

Table 2: *Input power [kW] of the tested combinations in the power matrix.*

		Tm[s]					
		3.5		**4.5**		**5.5**	
Hm0[m]	**0.25**	0	-0.9	0.1	-1.3		
	0.75	2.2	0.9	3.2	1.5		
	1.25	6.5	4.9	9.3	7.5		
	1.75			17.6	16.0	16.1	14.8
	2.25			26.6	24.9	26.0	24.2
	2.75					34.5	32.6

Table 3: *Output power [kW] of the tested combinations in the power matrix.*

Future tasks

Status	Task description
	To finalize old tasks.
Status	**Old tasks from previous status reports**
To do	Deeper analysis of why Bucher performs better than Parker in terms of efficiency.
To do	Minimization of the force oscillations between force steps
To do	Modification of FSA algorithm (or new algorithm) to achieve a better balance between efficiency and mechanical stress.
To do	Simulation of efficiency vs. cylinder velocity
To do	Optimization of Hp pressure for each seastate
To do	Comparison of measurements with simulations (where the hydraulics are modelled)

Appendix (Control parameters of the power matrix and seastate probabilities)

		Tm[s]		
		3.5	**4.5**	**5.5**
Hm0[m]	**0.25**	(5.0e5,-8.8e5)	(5.0e5,-13.8e5)	
	0.75	(5.0e5,-8.8e5)	(7.5e5,-13.8e5)	
	1.25	(5.0e5,-8.8e5)	(7.5e5,-13.8e5)	
	1.75		(8.8e5,-13.8e5)	(12.6e5,-11.0e5)
	2.25		(8.8e5,-11.3e5)	(15.1e5,-13.8e5)
	2.75			(16.3e5,-11.3e5)

Table A.1: *Control parameters (Bc,Kc) of the tested combinations in the power matrix.*

		Tm[s]		
		3.5	**4.5**	**5.5**
Hm0[m]	**0.25**	Out of water	Out of water	
	0.75	23.3	14.6	
	1.25	8.3	20.6	
	1.75		13.3	7.1
	2.25		3.8	4.9
	2.75			4.1

Table A.2: *Probabilities of the sea states where the manifold is supposed to be active.*

Appendix (Methods to calculate the input and output power and efficiency of the manifold)

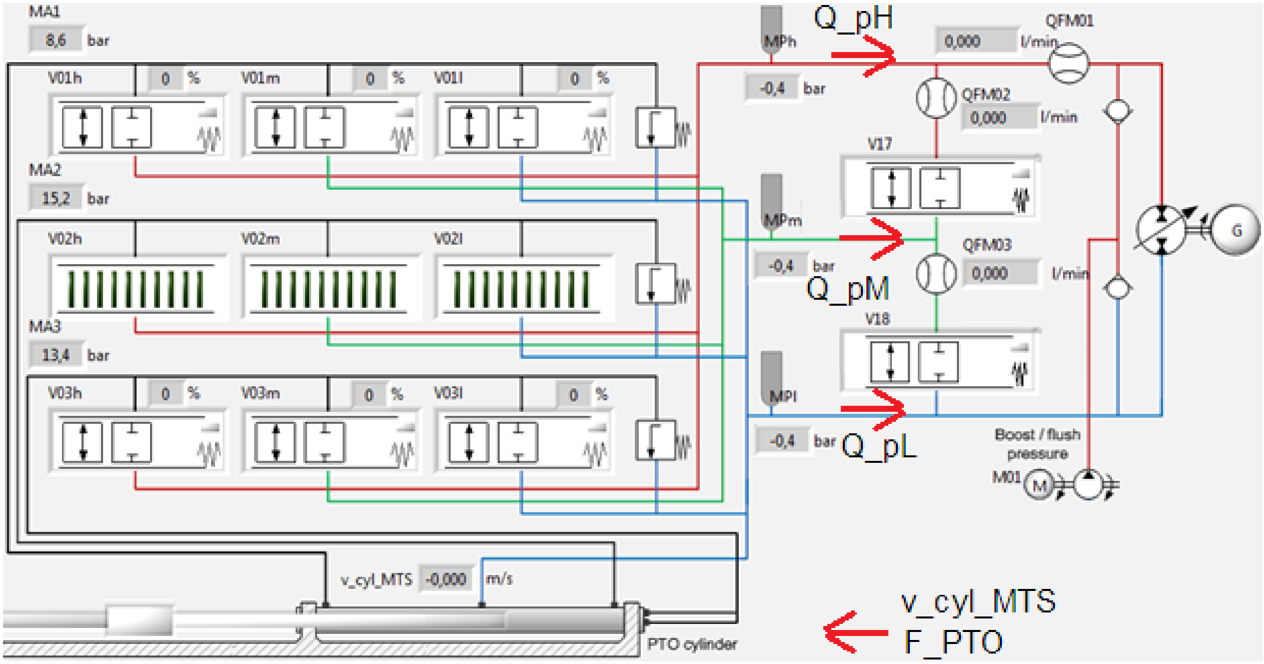

Figure 1: *Simplified HMI screen dump showing the variables to calculate the input and output power and efficiency of the manifold.*

```
%%  -------------------
%%  PSEUDO-CODE LISTING
%%  -------------------
Ts          = sampling time of measurements. % [s]
elapsedTime= elapsed time of measurements.  % [s]


% Cylinder areas
A1          = 0.0235; % [m^2] -
A2          = 0.0122; % [m^2] +
A3          = 0.0087; % [m^2] +

%% Input power
% Force feed-forward [N] to wave control
F_PTO = -MA1*A1 + MA2*A2 + MA3*A3; % [N]

P_in          = - F_PTO * v_cyl_MTS;
E_in        = sum(P_in)*Ts ;
P_in_avg    = E_in /elapsedTime;

%% Flow in pressure lines
Q_pH = QFM02 - QFM01;
Q_pM = QFM03 - QFM02;

Q_pL_A1     = (V1l)>0.5) * A1 * v_cyl_MTS; % [m^3/s]
Q_pL_A2     = (V2l)>0.5) * A2 * v_cyl_MTS; % [m^3/s]
Q_pL_A3     = (V3l)>0.5) * A3 * v_cyl_MTS; % [m^3/s]
```

```
Q_pL = Q_pL_A1 - Q_pL_A2 - Q_pL_A3; % [m^3/s]

%% Output power (FIRST METHOD)
P_pH1      = Q_pH * (MPh - mean(MPl)); % [W]
P_pM1      = Q_pM * (MPm - mean(MPl)); % [W]
P_out1     = P_pH1 + P_pM1;

E_out1     = sum(P_out1)*Ts;  % [J]
P_out_avg1 = E_out1 /elapsedTime; % [W]


%% Output power (SECOND METHOD)
P_pH2      = Q_pH * MPh; % [W]
P_pM2      = Q_pM * MPm; % [W]
P_pL2      = Q_pL * MPl; % [W]
P_out2     = P_pH2 + P_pM2 + P_pL2; % [W]

E_out2     = sum(P_out2)*Ts;  % [J]
P_out_avg2 = E_out2 / elapsedTime; % [W]

%% Efficiency calculations
eta1 = P_out_avg1/P_in_avg; % [0..1]
eta2 = P_out_avg2/P_in_avg; % [0..1]

%% Average of 1st and 2nd method (best guess)
P_out_avg = mean([P_out_avg1, P_out_avg2]);
eta       = mean([eta1, eta2]);
```

Appendix (Screen dumps of sensor calibration)

Everything stopped and without pressure (reference measurement for sensors) 2014-12-08.

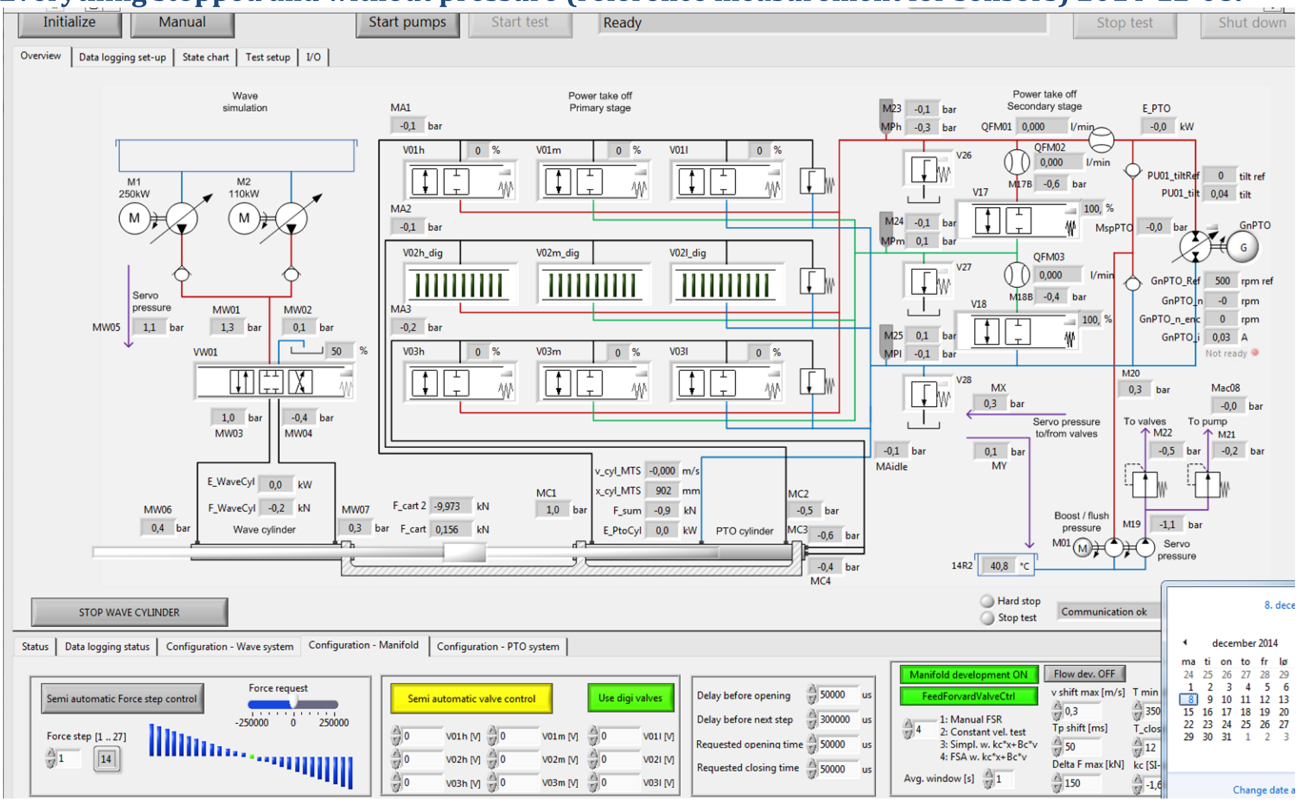

Figure 2: *Screen dump 1.*

"Idle" V01l, V02l and V03l open 40% for pressure equalizing, V17 and V18 closed, tilt 0.0: Flow 0 l/min.

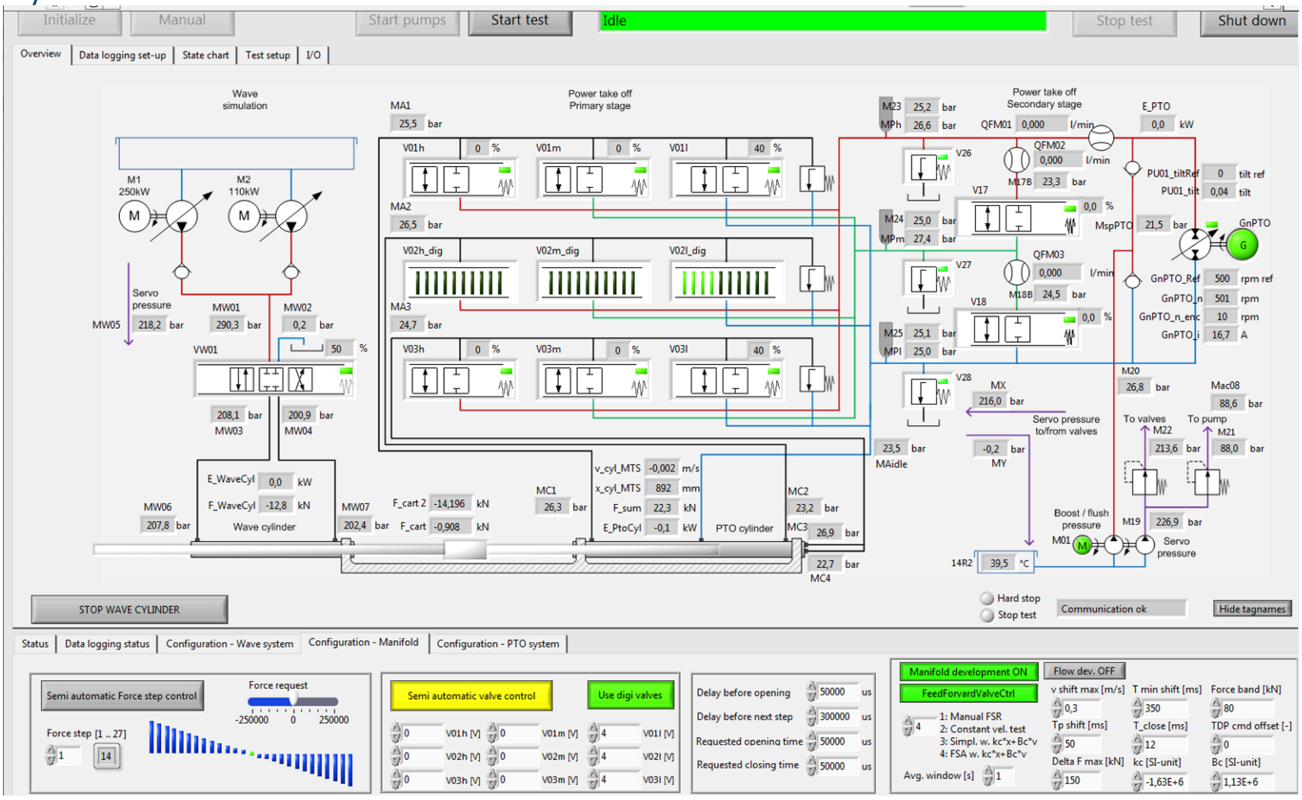

Figure 3: *Screen dump 2.*

Running in "Idle", V17 and V18 open 100% to check flow sensors. Tilt at 0.2: Pressure and flow equalizing.

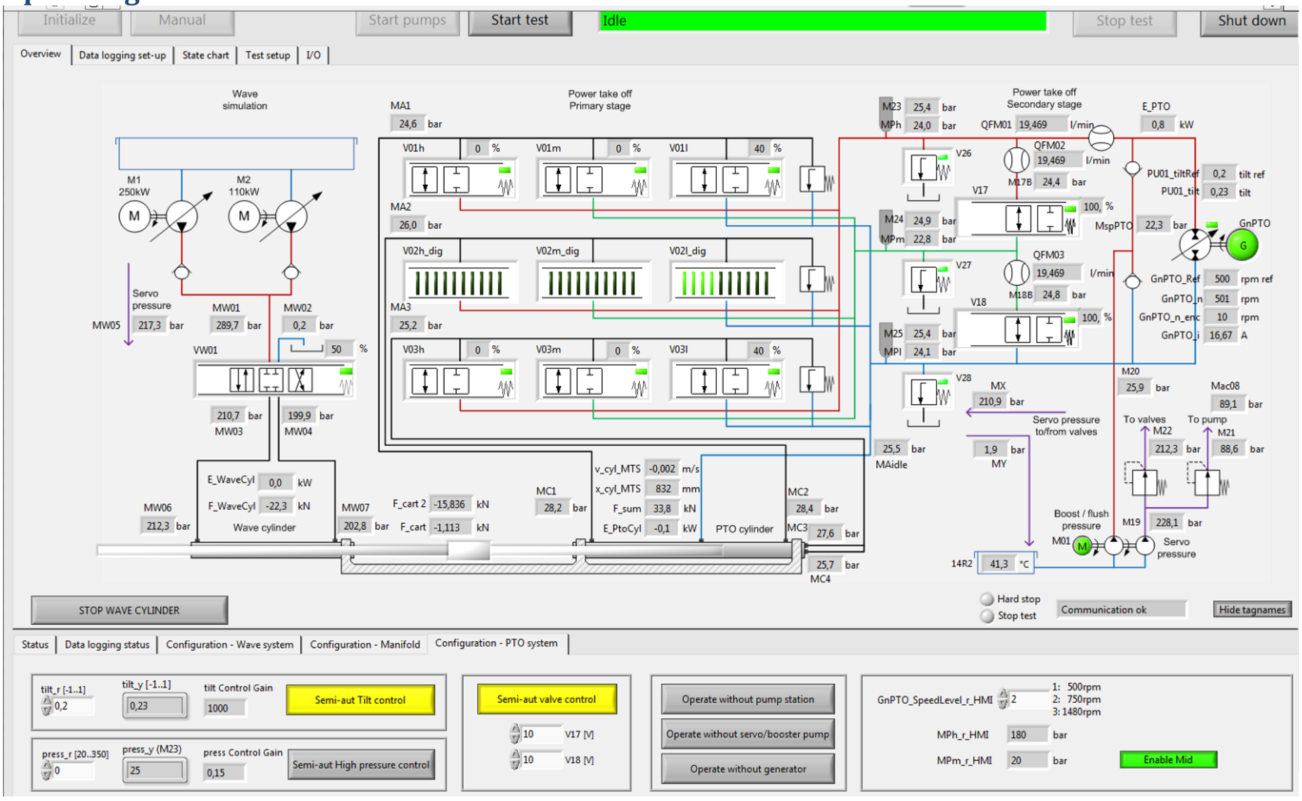

Figure 4: *Screen dump 3.*

Tilt changed to 0.5. V17 and V18 open 100%: Pressure and flow equalizing.

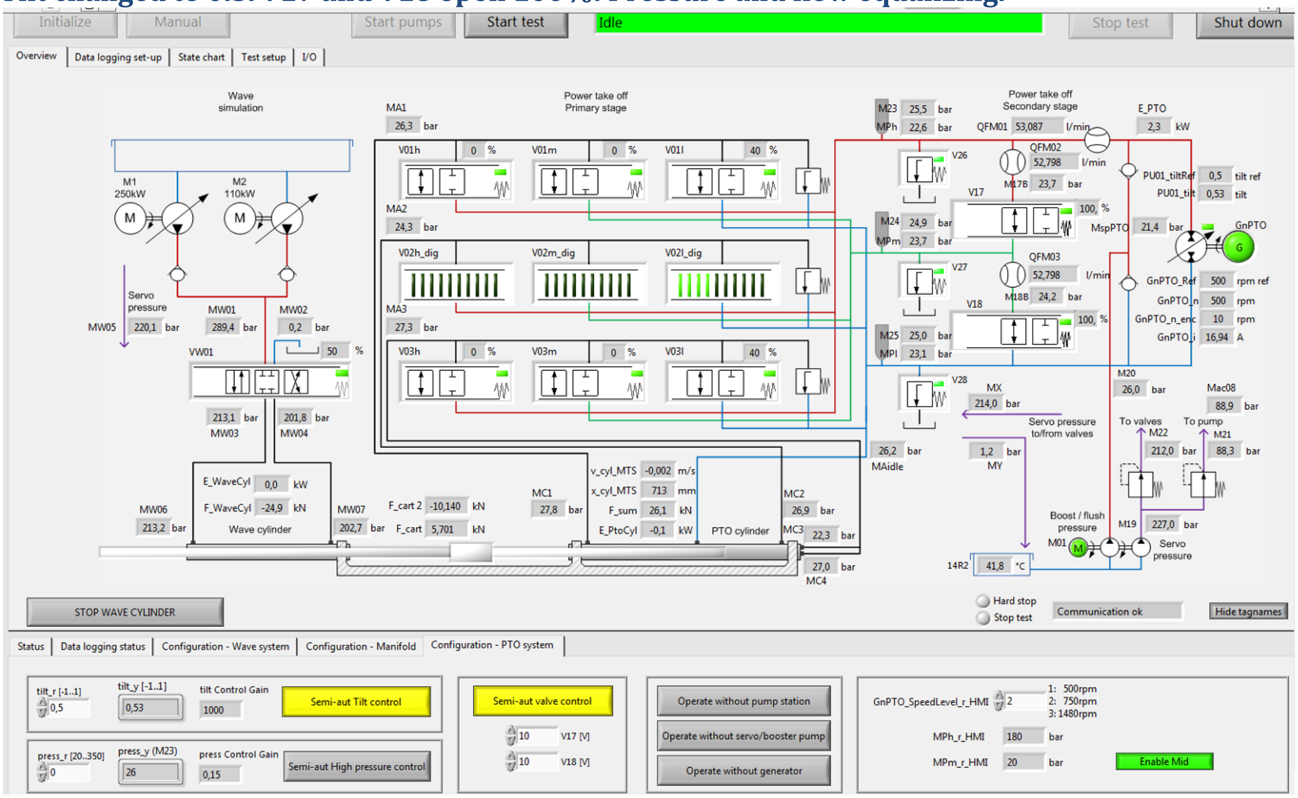

Figure 5: *Screen dump 4.*

Tilt changed to 0.8. V17 and V18 open 100%: Pressure and flow equalizing.

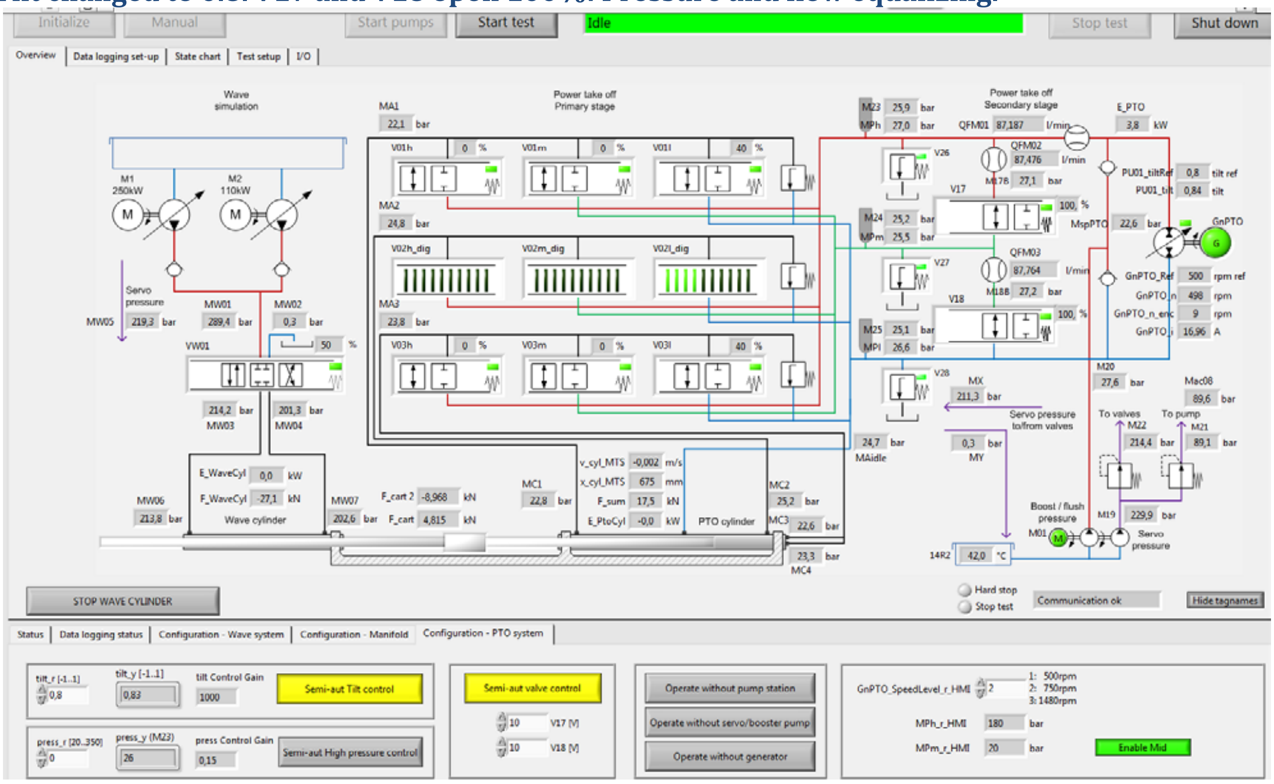

Figure 6: *Screen dump 5.*

Tilt changed to 1.0. V17 and V18 open 100%: Pressure and flow equalizing.

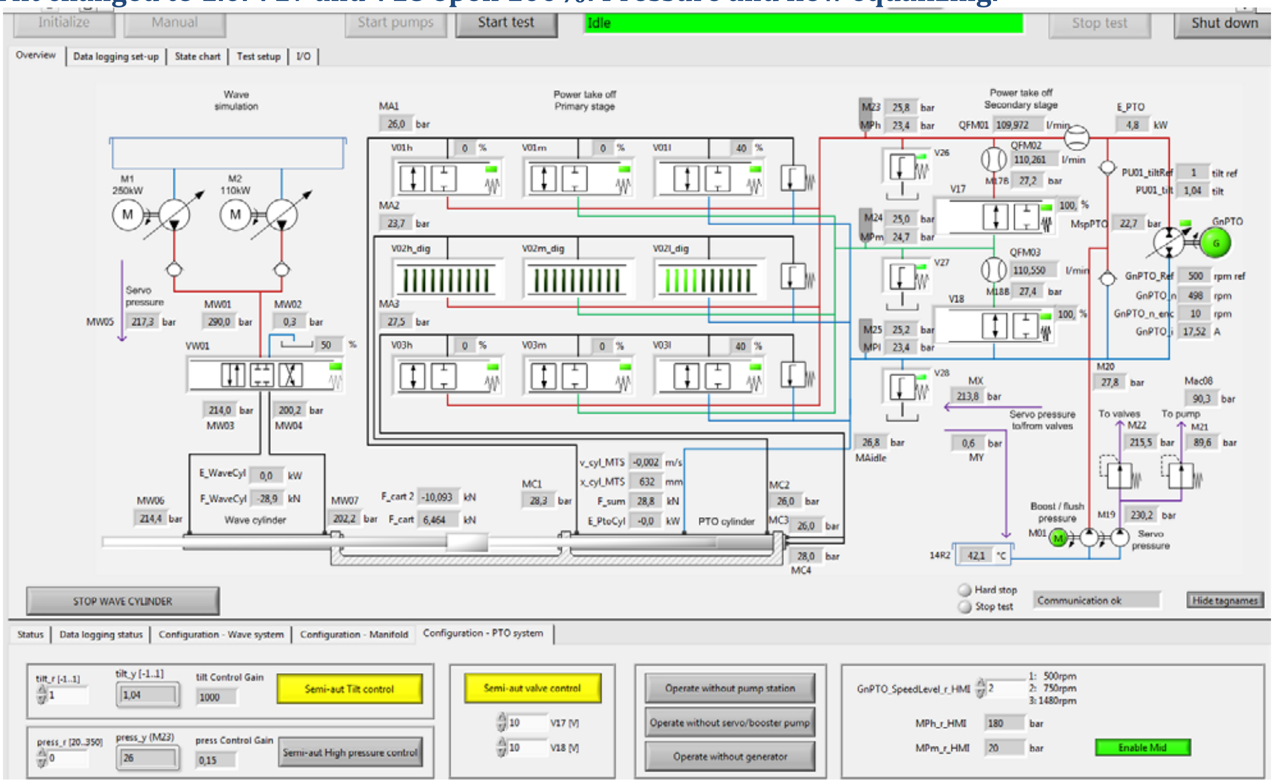

Figure 7: *Screen dump 6.*

Tilt changed to 0.02. V17 and V18 open 100%: Pressure and flow equalizing.

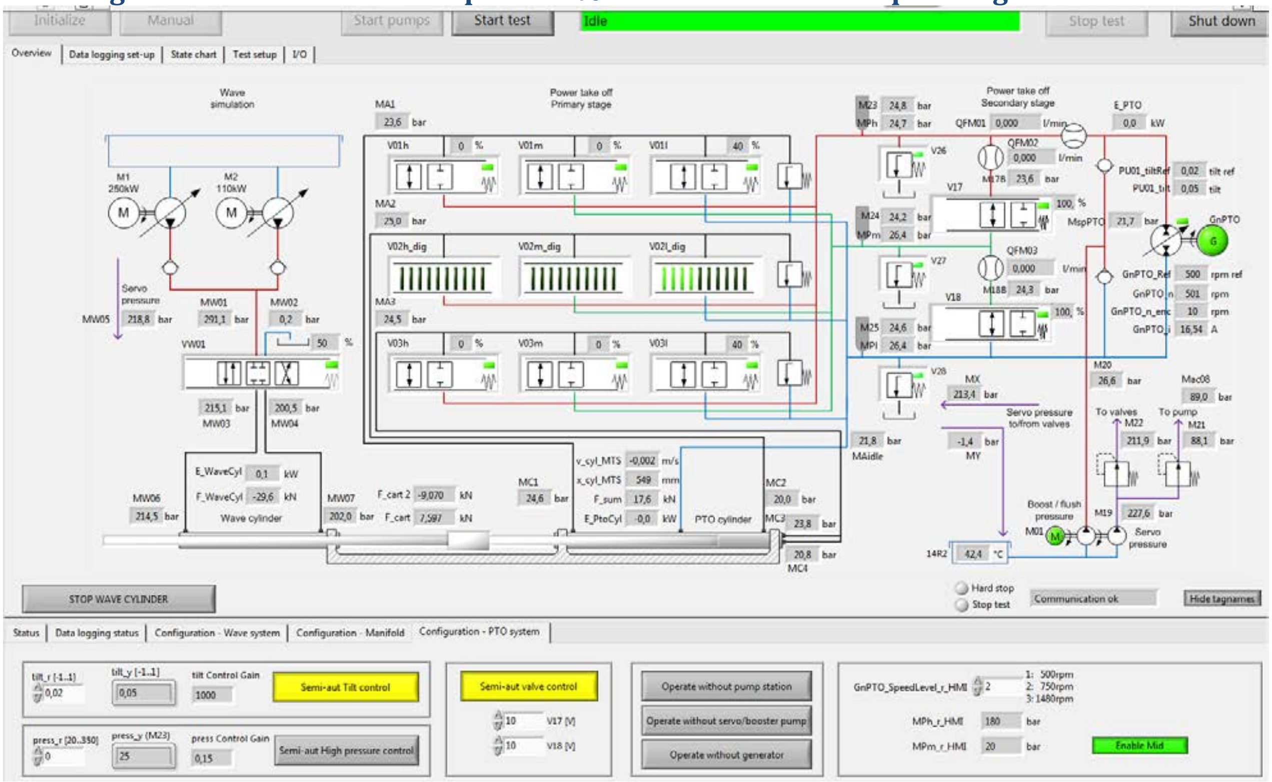

Figure 8: *Screen dump 7.*

Tiltcontrol disabled and pressure control enabled. V17 and V18 closed, all valves in manifold closed.

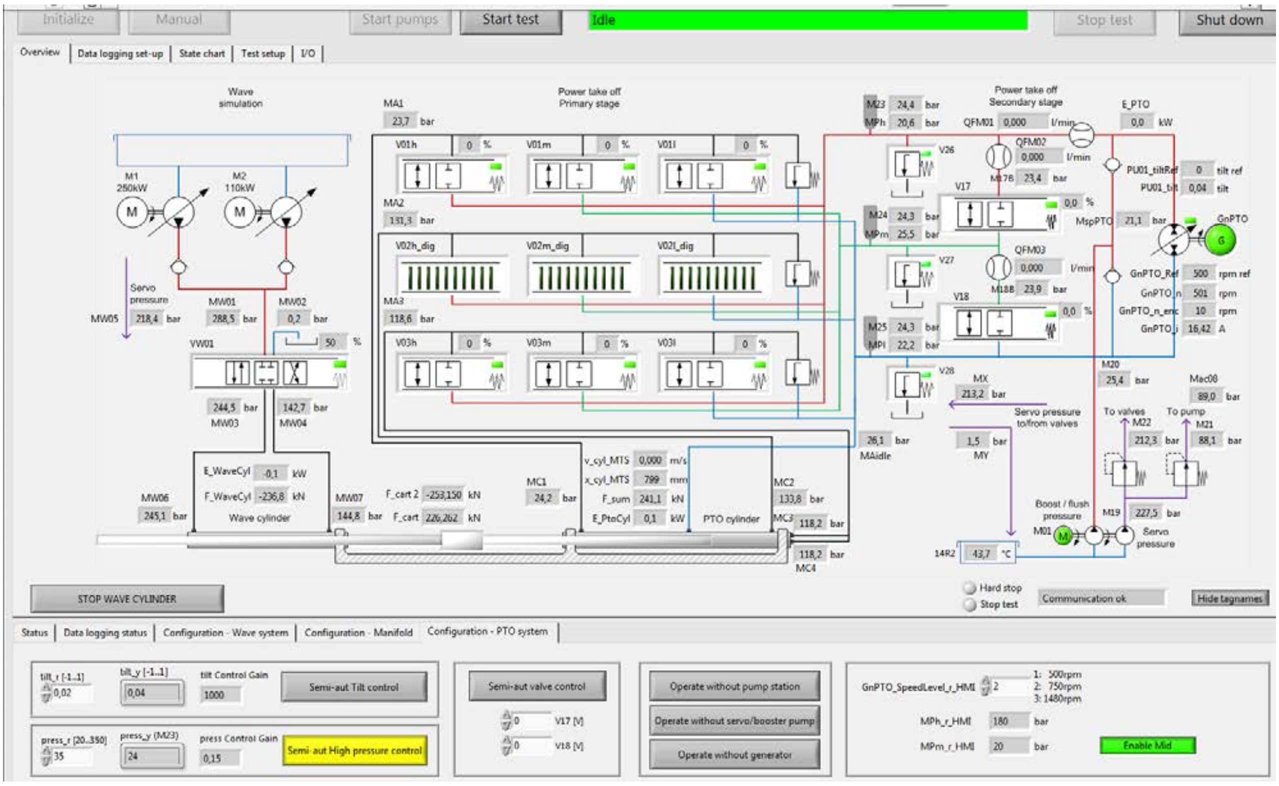

Figure 9: *Screen dump 8.*

Check of MTS sensor (cylinder position and velocity).

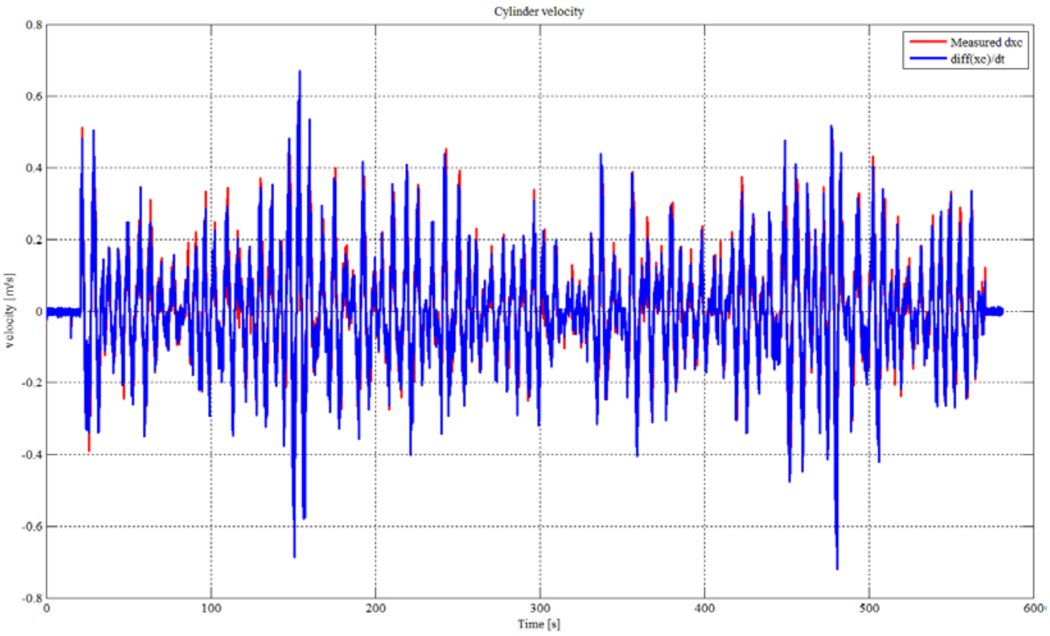

Figure 10: *Measured cylinder velocity (red) and differentiated position (blue).*

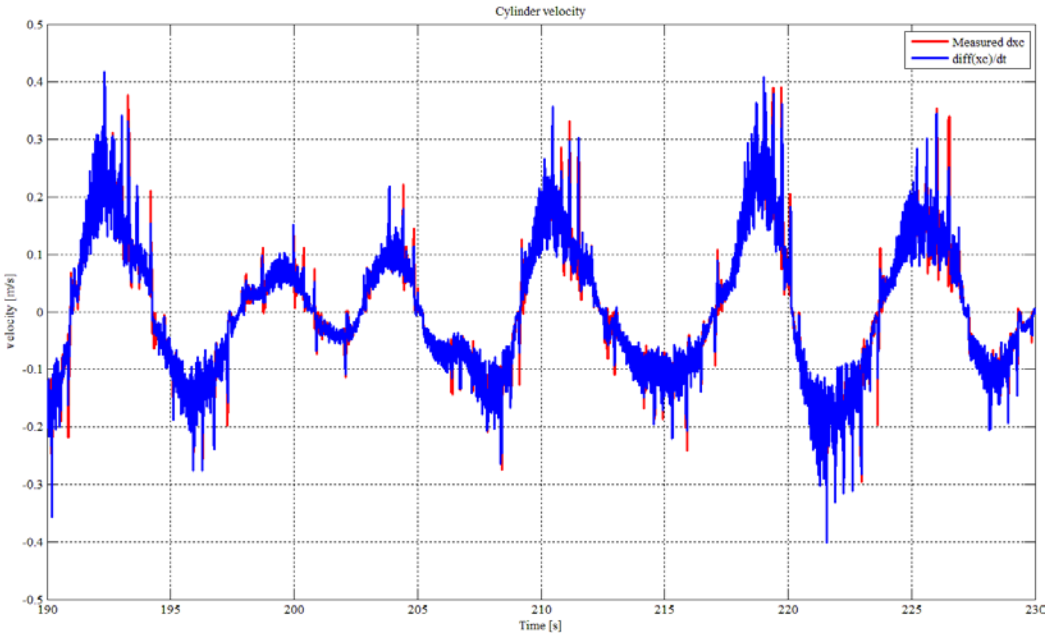

Figure 11: Zoom *of measured cylinder velocity (red) and differentiated position (blue).*