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Solenoid Model A 3.1

Several solenoid model schemes were evaluated with the purpose of finding a suitable simplified model. All solenoid models were compiled into a submodel structure, thereby allowing it's use in subsequent models and the easy substitution and evaluation of different models. Expectations were confirmed that the solenoid magnetic circuit greatly contributed to the overall valve dynamic behaviour. A model attempting to calculate the MMF (Magneto Motive Force) was constructed from a software demonstration model [MATLAB 1998 (a)]. It included effects such as nonlinear steel properties and air gap losses.

Not having much success with the MMF model implementation and programming difficulties, prompted the use of an exponential rise and decay model, that provides solenoid force as an output (independent of poppet position). The time constant can be adjusted to give the desired rise and fall times. After matching valve performance trends with dynamic experimental trends, the model was expanded to include a fixed base delay (separate values for opening and closing).

Other methods commonly used to simulate solenoids include a lookup table with measured solenoid force versus displacement, simple first order lag networks and transfer functions [Tomlinson & Tilley 1993][Handroos & Vilenius 1991] In the literature it was found that advanced mathematical tools (e.g. FEM) are used in the design of solenoid valves. It is foreseen that an improved solenoid model will improve the performance of the model in this study.

A3.1.1 MMF solenoid model equations

For most of the parameters in this model it were impossible or impractical to get true values and most of the MATLAB example parameter values were used. The equations were implemented in AMESim by using standard AMESim control library components. The equations aimed to include hysteresis effects in the steel. This is modelled by increasing and decreasing flux density (B) versus magnetic field intensity (H) values, but proved difficult to implement and the mean value of this curve was used instead (thereby disregarding hysteresis effects). A SIMULINK version of this model was also created to aid in investigations.

The equations take solenoid voltage as user-input together with current and air gap length as feedback variables. This adds flux (ϕ) as another state variable. Most of the magnetic losses are in the air gap. For this reason the current air gap size is of importance. Significant losses can also be obtained in the steel section. For this reason a lookup table containing steel properties is included (values for this table in annexure A3.3.5).

$$\dot{\phi} = \frac{V_{sol} - i \cdot R}{N}$$

$$B = \frac{\phi}{A}$$

$$H_{steel} = f(B) \qquad \text{(Lookup table)}$$

$$H_{air} = \frac{B}{\mu_0}$$

$$MMF_{steel} = H_{steel} \cdot L_{steel}$$

$$MMF_{air} = H_{air}(x_{max} + offset - x)$$

$$MMF = MMF_{steel} + MMF_{air}$$

$$i = \frac{MMF}{N}$$

$$F_{sol} = \frac{B^2 \cdot A}{2\mu_0}$$

(Eqs A3.1.1)

Variables in eqs A3.1.1:

ϕ = Flux
V_{sol} = Solenoid voltage
i = Solenoid coil current
R = Winding resistance
N = Number of turns in the coil
MMF = Magnetomotive force
H = Magnetic field intensity
x_{max} = Maximum armature travel
offset = Minimum air gap left (MUST be > 0)
x = Armature motion
L_{steel} = Magnetic circuit length in steel.
B = Flux density
A = Air gap cross sectional area
μ_0 = Permeability of air
F_{sol} = Solenoid force

The steel H vs B values are shown in figure A3.1.1. Hysteresis effects are included in the form of two trends, although not visible in the figure, due to scaling. Implementation of the MMF solenoid model equations in AMESim is shown in figure A3.1.2.

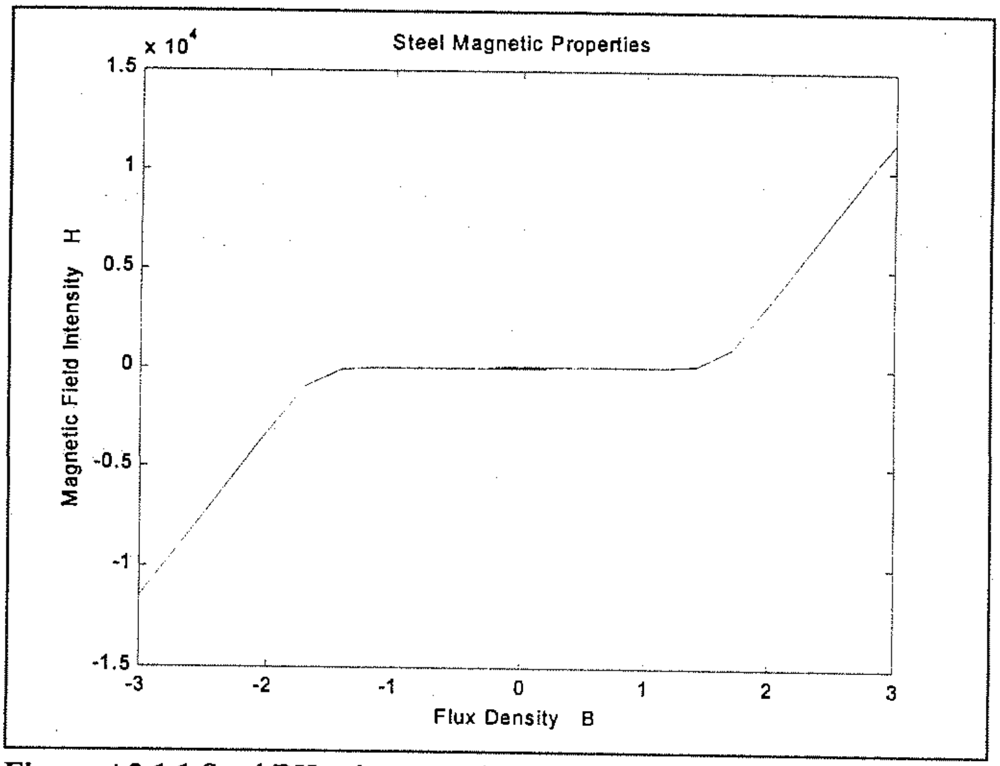

Figure A3.1.1 Steel BH values, as taken from the MATLAB example

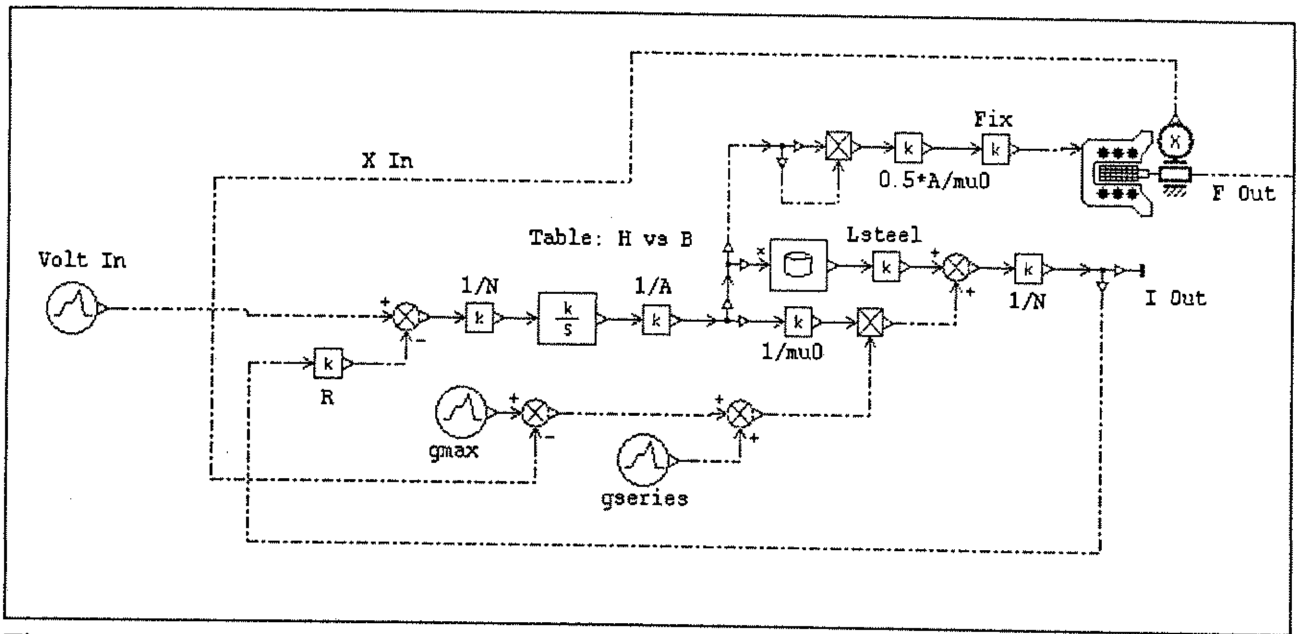

Figure A3.1.2 AMESim implementation of the MMF solenoid equations (without hysteresis)

A3.1.2 Exponential solenoid model

The exponential solenoid force model was implemented and used in the final MATLAB and AMESim models. The model has 5 parameters available for adjustment, thereby drastically reducing the need for parameter adjustment. These parameters are: Opening and closing time constants. Opening and closing base delay values and the maximum solenoid force obtainable. The exponential solenoid equations are in the form of eq A3.1.2, although computer implementation is much more intricate to allow for an arbitrary user specified opening and closing sequence. Attempts were made to include the solenoid force as a trend being watched for discontinuities (using the MATLAB 'zerocross' function) but no significant increase in solver efficiency was noticed.

(Eq A3.1.2)

$$F_{sol} = F_{max} - F_{max} \cdot e^{-\left(\frac{t - ton}{\tau_{on}}\right)}$$

Variables:
F_{sol} = Calculated solenoid force
F_{max} = Maximum solenoid force allowed
t = current simulation time
t_{on} = User specified time for solenoid switch over
τ_{on} = time constant for the exponential curve

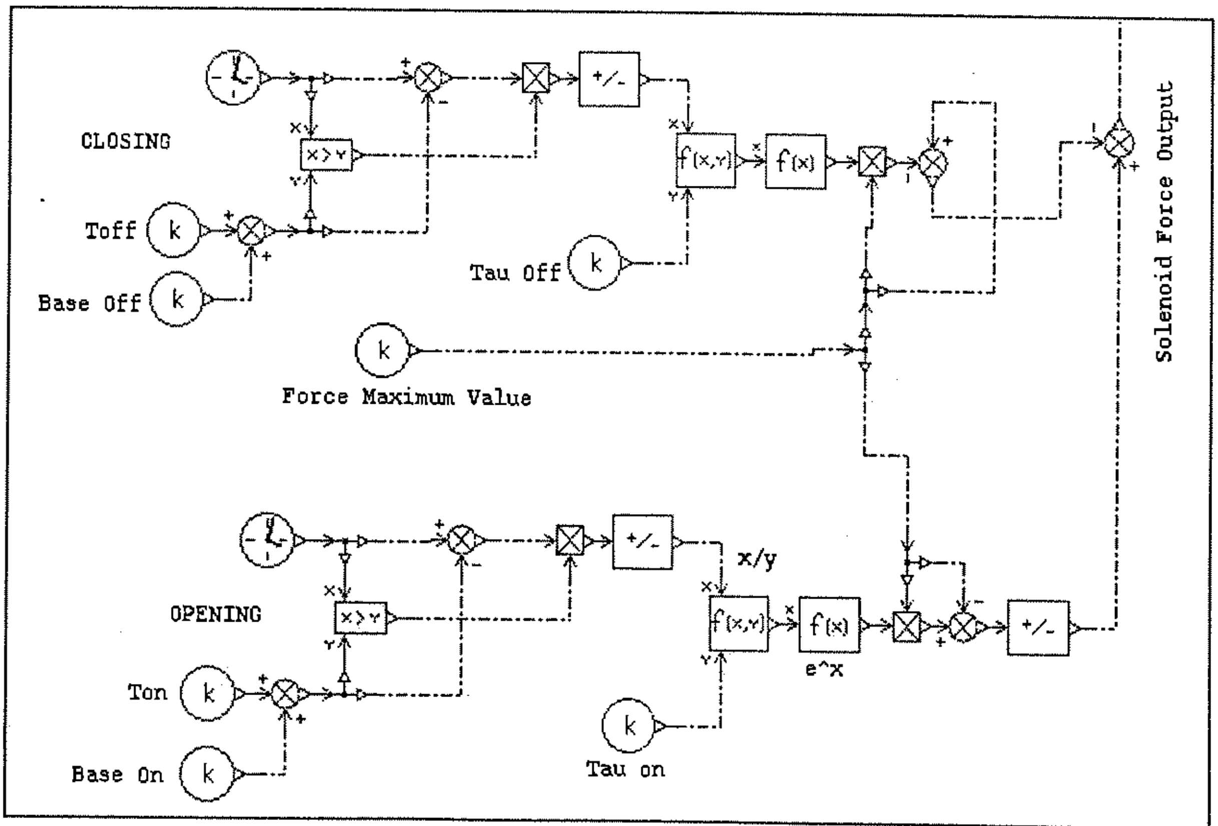

Figure A3.1.3 Exponential solenoid force model, as implemented in AMESim.

Model Parameters — A 3.2

The aim of this annexure is to provide a future reference to the parameters and their values used in the AMESim and MATLAB models. Parameters are given in the form of AMESim model definition files and, therefore, include more parameters than used in the MATLAB models.

Information of the following models are included:

- A single test bench supply pipe.
- Pilot valve model
- System with damper model

In the pilot valve and valve system models, the test bench supply pipe parameters have been removed to prevent duplicate information in the tables and are shown in the separate pipe model paragraph.

For each of these models the following is given:

- System layout figure. This figure includes labels of the submodels. These labels are somewhat overlapping, but do provide an indication of the labels in the subsequent tables. The online AMESim help file gives a detail description of the models and their associated mathematics.
- Table of parameters used in the AMESim model. The purpose of this table is to give insight into the number of parameters available for adjustment and to facilitate future simulation and/or analysis work

A3.2.1 Spring stiffness calculation

The pilot valve and logic element spring stiffness was calculated according to Shigley (1986) with equation A3.2.1

Eq A3.2.1

$$k = \frac{d^4 G}{8D^3 (N_T - N_D)}$$

Parameter	LC25 spring	WSE 3 spring
G	80×10^9	
D	0.0136+0.0018	0.0022+0.0008
d	0.0018	0.0008
NT	9.75	6.6
ND	2	1
Result (k)	3 708 [N/m]	27 089 [N/m]

A 3.2.2 Single isolated test bench supply pipe

This model is discussed in paragraph 3.6.

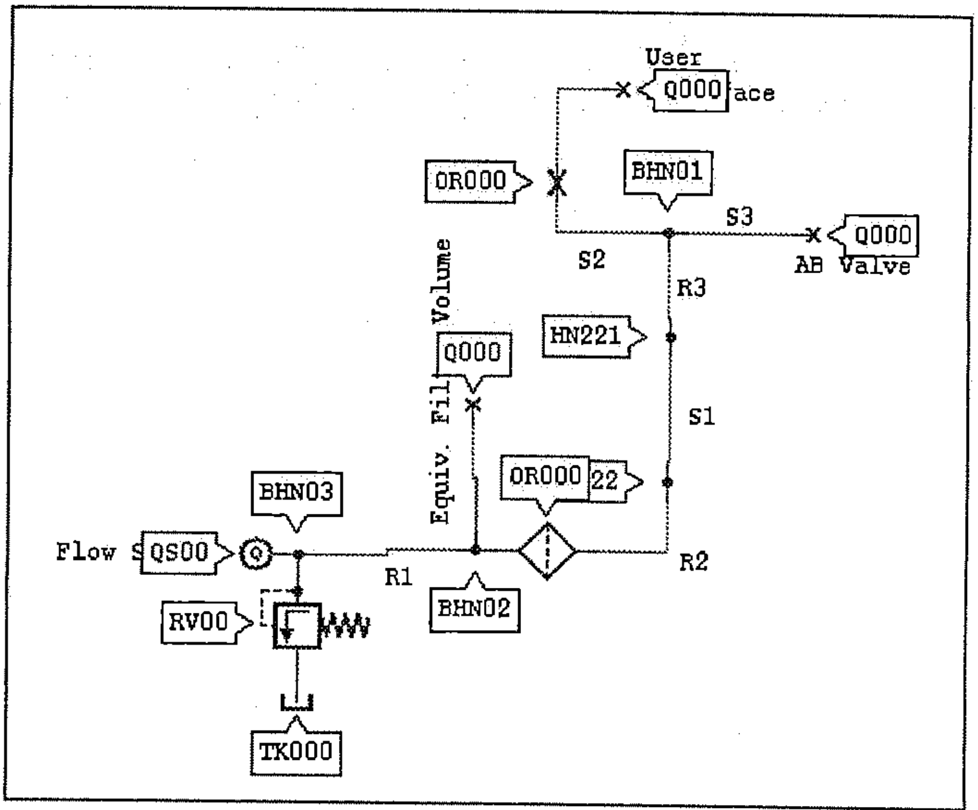

Figure A 3.2.1 Isolated test bench supply pipe model in AMESim

Parameters pertaining to the isolated test bench supply pipe model:

-1.0000E-03	SPR0 instance 1 initial spring displacement [m]
2.7089E+04	SPR0 instance 1 spring rate [N/m]
0.0000E+00	SPR0 instance 1 displacement giving zero spring force [m]
0.0000E+00	SPR0 instance 1 force at port 2 [N]
3.0000E+00	BAP22 instance 1 seat diameter [mm]
4.0000E+00	BAP22 instance 1 ball diameter [mm]
4.0000E+00	BAP22 instance 1 rod diameter (opposite to seat) [mm]
0.0000E+00	BAP22 instance 1 rod diameter (seat side) [mm]
0.0000E+00	BAP22 instance 1 jet forces coefficient [null]
6.0000E-01	BAP22 instance 1 maximum flow coefficient [null]
1.0000E+03	BAP22 instance 1 critical flow number [null]
9.0000E-01	BAP22 instance 1 opening (underlap) corresponding to zero displacement [mm]
0.0000E+00	BAP22 instance 1 opening for minimum area [mm]
9.0000E-01	BAP22 instance 1 opening for maximum area [mm]
4.0000E-01	BAP22 instance 1 volume at port 1 corresponding to zero lift [cm**3]
8.0000E-01	BAP22 instance 1 volume at port 2 corresponding to zero lift [cm**3]
2.8000E+00	BAP21 instance 1 seat diameter [mm]
4.0000E+00	BAP21 instance 1 ball diameter [mm]
4.0000E+00	BAP21 instance 1 rod diameter (opposite to seat) [mm]
1.5000E+00	BAP21 instance 1 rod diameter (seat side) [mm]
0.0000E+00	BAP21 instance 1 jet force coefficient [null]
4.3000E-01	BAP21 instance 1 maximum flow coefficient [null]
1.0000E+02	BAP21 instance 1 critical flow number [null]
0.0000E+00	BAP21 instance 1 opening (underlap) corresponding to zero displacement [mm]
0.0000E+00	BAP21 instance 1 opening for minimum area [mm]
9.0000E-01	BAP21 instance 1 opening for maximum area [mm]
4.0000E-01	BAP21 instance 1 volume at port 1 corresponding to zero lift [cm**3]

8.0000E-01	BAP21 instance 1 volume at port 2 corresponding to zero lift [cm**3]
2.0000E-02	BAI21 instance 1 mass [kg]
0.0000E+00	BAI21 instance 1 stiction friction force (static) [N]
0.0000E+00	BAI21 instance 1 Coulomb friction force (dynamic) [N]
2.0000E+02	BAI21 instance 1 viscous friction [N/(m/s)]
0.0000E+00	BAI21 instance 1 windage friction [N/(m/s)**2]
1.0000E-06	BAI21 instance 1 stick velocity threshold [m/s]
1.0000E-03	BAI21 instance 1 Stribeck time constant [s]
0.0000E+00	BAI21 instance 1 lower displacement limit [m]
9.0000E-04	BAI21 instance 1 higher displacement limit [m]
0.0000E+00	BAI21 instance 1 inclination (+90 port 1 lowest -90 port 1 highest) [degree]
0.0000E+00	BAI21 instance 1 velocity port 2 [m/s]
5.0000E-04	BAI21 instance 1 displacement port 2 [m]
2.8000E+00	BAP12 instance 1 piston diameter [mm]
0.0000E+00	BAP12 instance 1 rod diameter [mm]
2.0000E+00	BAP12 instance 1 chamber length at zero displacement [mm]
3.0000E-03	CONS0 instance 1 constant value [null]
x/y	FXY0 instance 1 expression for output in terms of x and y
exp(x)	FX00 instance 1 expression in terms of the input x
4.0000E-02	CONS0 instance 2 constant value [null]
x/y	FXY0 instance 2 expression for output in terms of x and y
exp(x)	FX00 instance 2 expression in terms of the input x
2.0000E+02	CONS0 instance 3 constant value [null]
2.5000E-02	CONS0 instance 4 constant value [null]
3.0000E+00	CONS0 instance 5 constant value [null]
1.0000E+00	CONS0 instance 6 constant value [null]
2.3000E-02	CONS0 instance 7 constant value [null]
0.0000E+00	TK000 instance 1 tank pressure [bar]
0.0000E+00	V000 instance 1 linear velocity (always zero) [m/s]
0.0000E+00	HN221 instance 1 volume port 1 [cm**3]
0.0000E+00	HN222 instance 1 volume port 2 [cm**3]
1.0000E+00	OR000 instance 1 characteristic flow rate [L/min]
1.0000E+00	OR000 instance 1 corresponding pressure drop [bar]
1.0000E+01	OR000 instance 1 equivalent orifice diameter [mm]
7.0000E-01	OR000 instance 1 maximum flow coefficient [null]
1.0000E+03	OR000 instance 1 critical flow number (laminar -> turbulent) [null]
1	OR000 instance 1 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	Q000 instance 1 flow rate (always zero) [L/min]
0.0000E+00	Q000 instance 2 flow rate (always zero) [L/min]
0.0000E+00	QS00 instance 1 time at which duty cycle starts [s]
1.2000E+01	QS00 instance 1 .flow rate at start of stage 1 [L/min]
1.2000E+01	QS00 instance 1 .flow rate at end of stage 1 [L/min]
3.0000E+01	QS00 instance 1 duration of stage 1 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 2 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 2 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 2 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 3 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 3 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 3 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 4 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 4 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 4 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 5 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 5 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 5 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 6 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 6 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 6 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 7 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 7 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 7 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 8 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 8 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 8 [s]
0.0000E+00	TK000 instance 2 tank pressure [bar]
1.0000E+00	OR000 instance 2 characteristic flow rate [L/min]
1.0000E+00	OR000 instance 2 corresponding pressure drop [bar]
3.0000E+00	OR000 instance 2 equivalent orifice diameter [mm]
7.0000E-01	OR000 instance 2 maximum flow coefficient [null]
4.0000E+02	OR000 instance 2 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 2 1 for pressure drop/flow rate pair 2 for orifice diameter

0.0000E+00	PT02 instance 1 offset to be subtracted from pressure [bar]
1.0000E+00	PT02 instance 1 gain for signal output [1/bar]
1.0000E+00	OR000 instance 3 characteristic flow rate [L/min]
1.0000E+00	OR000 instance 3 corresponding pressure drop [bar]
5.0000E+00	OR000 instance 3 equivalent orifice diameter [mm]
5.4000E-01	OR000 instance 3 maximum flow coefficient [null]
2.0000E+03	OR000 instance 3 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 3 1 for pressure drop/flow rate pair 2 for orifice diameter
1.0760E+02	RV00 instance 1 relief valve cracking pressure [bar]
1.0000E+04	RV00 instance 1 relief valve flow rate pressure gradient [L/min/bar]
0.0000E+00	TK000 instance 3 tank pressure [bar]
9.0000E+01	OR000 instance 4 characteristic flow rate [L/min]
5.0000E+00	OR000 instance 4 corresponding pressure drop [bar]
6.0000E+00	OR000 instance 4 equivalent orifice diameter [mm]
5.0000E-01	OR000 instance 4 maximum flow coefficient [null]
4.0000E+02	OR000 instance 4 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 4 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	HN222 instance 2 volume port 2 [cm**3]
0.0000E+00	PT03 instance 1 offset to be subtracted from pressure [bar]
1.0000E+00	PT03 instance 1 gain for signal output [1/bar]
0.0000E+00	HN221 instance 2 volume port 1 [cm**3]
0.0000E+00	HN221 instance 3 volume port 1 [cm**3]
5.0000E-01	BHC11 instance 1 dead volume [cm**3]
5.0000E+01	BHC11 instance 1 pressure port 1 [bar]
0.0000E+00	BZQV0 instance 1 zero flow rate [L/min]
0.0000E+00	BZQV0 instance 1 zero volume [cm**3]
1.0000E+00	BHO11 instance 1 characteristic flow rate [L/min]
1.0000E+00	BHO11 instance 1 corresponding pressure drop [bar]
3.0000E+00	BHO11 instance 1 equivalent orifice diameter [mm]
4.0000E-01	BHO11 instance 1 maximum flow coefficient [null]
2.0000E+02	BHO11 instance 1 critical flow number (laminar -> turbulent) [null]
2	BHO11 instance 1 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	BHO11 instance 1 zero volume source [cm**3]
0.0000E+00	BHO11 instance 1 zero volume source [cm**3]
2.0000E+01	HL000 instance 1 diameter of pipe [mm]
6.0000E-02	HL000 instance 1 pipe length [m]
0.0000E+00	HL000 instance 1 wall thickness [mm]
2.0600E+06	HL000 instance 1 Young's modulus for material [bar]
1.7000E+04	HL000 instance 1 user specified effective bulk modulus [bar]
1	HL000 instance 1 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL000 instance 1 pressure at port 1 [bar]
2.4000E+01	HL06 instance 1 diameter of pipe [mm]
5.2000E+00	HL06 instance 1 pipe length [m]
1.0000E-05	HL06 instance 1 relative roughness [null]
0.0000E+00	HL06 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
3.0000E+00	HL06 instance 1 wall thickness [mm]
2.0600E+06	HL06 instance 1 Young's modulus for material [bar]
1.7000E+04	HL06 instance 1 user specified effective bulk modulus [bar]
1	HL06 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL06 instance 1 pressure at port 1 [bar]
0.0000E+00	HL06 instance 1 pressure at port 2 [bar]
0.0000E+00	HL06 instance 1 flow rate at centre of pipe [L/min]
2.8000E+01	HL01 instance 1 diameter of pipe [mm]
1.0000E+00	HL01 instance 1 pipe length [m]
1.0000E-05	HL01 instance 1 relative roughness [null]
0.0000E+00	HL01 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL01 instance 1 wall thickness [mm]
1.0000E+04	HL01 instance 1 Young's modulus for material [bar]
1.7000E+04	HL01 instance 1 user specified effective bulk modulus [bar]
1	HL01 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 1 pressure at port 1 [bar]
8.0000E+01	HL03 instance 1 diameter of pipe [mm]
3.0000E-01	HL03 instance 1 pipe length [m]
1.0000E-05	HL03 instance 1 relative roughness [null]
0.0000E+00	HL03 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
1.0000E+01	HL03 instance 1 wall thickness [mm]
2.0600E+06	HL03 instance 1 Young's modulus for material [bar]
1.7000E+04	HL03 instance 1 user specified effective bulk modulus [bar]
1	HL03 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL03 instance 1 pressure at port 1 [bar]
0.0000E+00	HL03 instance 1 pressure at port 2 [bar]

2.3000E+01	HL04 instance 1 diameter of pipe [mm]
3.3000E+00	HL04 instance 1 pipe length [m]
1.0000E-05	HL04 instance 1 relative roughness [null]
0.0000E+00	HL04 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL04 instance 1 wall thickness [mm]
1.0000E+04	HL04 instance 1 Young's modulus for material [bar]
1.7000E+04	HL04 instance 1 user specified effective bulk modulus [bar]
1	HL04 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL04 instance 1 pressure at port 1 [bar]
0.0000E+00	HL04 instance 1 flow rate at port 2 [L/min]
5.0000E+00	HL01 instance 2 diameter of pipe [mm]
8.0000E-02	HL01 instance 2 pipe length [m]
1.0000E-05	HL01 instance 2 relative roughness [null]
0.0000E+00	HL01 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 2 wall thickness [mm]
2.0600E+06	HL01 instance 2 Young's modulus for material [bar]
1.7000E+04	HL01 instance 2 user specified effective bulk modulus [bar]
1	HL01 instance 2 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL01 instance 2 pressure at port 1 [bar]
5.0000E+00	HL01 instance 3 diameter of pipe [mm]
6.0000E-02	HL01 instance 3 pipe length [m]
1.0000E-05	HL01 instance 3 relative roughness [null]
0.0000E+00	HL01 instance 3 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 3 wall thickness [mm]
2.0600E+06	HL01 instance 3 Young's modulus for material [bar]
1.7000E+04	HL01 instance 3 user specified effective bulk modulus [bar]
1	HL01 instance 3 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL01 instance 3 pressure at port 1 [bar]
4.0000E+00	HL01 instance 4 diameter of pipe [mm]
8.0000E-02	HL01 instance 4 pipe length [m]
1.0000E-05	HL01 instance 4 relative roughness [null]
0.0000E+00	HL01 instance 4 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 4 wall thickness [mm]
2.0600E+06	HL01 instance 4 Young's modulus for material [bar]
1.7000E+04	HL01 instance 4 user specified effective bulk modulus [bar]
1	HL01 instance 4 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL01 instance 4 pressure at port 1 [bar]
6.0000E+00	HL03 instance 2 diameter of pipe [mm]
6.0000E-01	HL03 instance 2 pipe length [m]
1.0000E-05	HL03 instance 2 relative roughness [null]
0.0000E+00	HL03 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
4.0000E+00	HL03 instance 2 wall thickness [mm]
4.0000E+04	HL03 instance 2 Young's modulus for material [bar]
1.7000E+04	HL03 instance 2 user specified effective bulk modulus [bar]
1	HL03 instance 2 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL03 instance 2 pressure at port 1 [bar]
1.0000E+01	HL03 instance 2 pressure at port 2 [bar]
1.5000E+01	HL01 instance 5 diameter of pipe [mm]
6.0000E-01	HL01 instance 5 pipe length [m]
1.0000E-05	HL01 instance 5 relative roughness [null]
0.0000E+00	HL01 instance 5 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
2.5000E+00	HL01 instance 5 wall thickness [mm]
2.0600E+06	HL01 instance 5 Young's modulus for material [bar]
1.7000E+04	HL01 instance 5 user specified effective bulk modulus [bar]
1	HL01 instance 5 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 5 pressure at port 1 [bar]
2.8000E+01	HL02 instance 1 diameter of pipe [mm]
5.0000E-01	HL02 instance 1 pipe length [m]
1.0000E-05	HL02 instance 1 relative roughness [null]
0.0000E+00	HL02 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL02 instance 1 wall thickness [mm]
1.0000E+04	HL02 instance 1 Young's modulus for material [bar]
1.7000E+04	HL02 instance 1 user specified effective bulk modulus [bar]
1	HL02 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL02 instance 1 pressure at mid-point [bar]
6.0000E+00	HL000 instance 2 diameter of pipe [mm]
6.0000E-01	HL000 instance 2 pipe length [m]
4.0000E+00	HL000 instance 2 wall thickness [mm]
1.0000E+04	HL000 instance 2 Young's modulus for material [bar]
1.7000E+04	HL000 instance 2 user specified effective bulk modulus [bar]
1	HL000 instance 2 1 for calculated bulk modulus value 2 for user specified value

5.0000E+01	HL000 instance 2 pressure at port 1 [bar]
2.5000E+01	HL000 instance 3 diameter of pipe [mm]
1.0000E+00	HL000 instance 3 pipe length [m]
1.0000E+01	HL000 instance 3 wall thickness [mm]
2.0600E+06	HL000 instance 3 Young's modulus for material [bar]
1.7000E+04	HL000 instance 3 user specified effective bulk modulus [bar]
1	HL000 instance 3 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL000 instance 3 pressure at port 1 [bar]
1.0000E+00	HL01 instance 6 diameter of pipe [mm]
3.0000E-02	HL01 instance 6 pipe length [m]
1.0000E-05	HL01 instance 6 relative roughness [null]
0.0000E+00	HL01 instance 6 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 6 wall thickness [mm]
2.0600E+06	HL01 instance 6 Young's modulus for material [bar]
1.7000E+04	HL01 instance 6 user specified effective bulk modulus [bar]
1	HL01 instance 6 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 6 pressure at port 1 [bar]
5.0000E+00	HL02 instance 2 diameter of pipe [mm]
5.0000E-02	HL02 instance 2 pipe length [m]
1.0000E-05	HL02 instance 2 relative roughness [null]
0.0000E+00	HL02 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
1.0000E+01	HL02 instance 2 wall thickness [mm]
2.0600E+06	HL02 instance 2 Young's modulus for material [bar]
1.7000E+04	HL02 instance 2 user specified effective bulk modulus [bar]
1	HL02 instance 2 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL02 instance 2 pressure at mid-point [bar]
3.0000E+00	HL01 instance 7 diameter of pipe [mm]
5.0000E-02	HL01 instance 7 pipe length [m]
1.0000E-05	HL01 instance 7 relative roughness [null]
0.0000E+00	HL01 instance 7 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 7 wall thickness [mm]
2.0600E+06	HL01 instance 7 Young's modulus for material [bar]
1.7000E+04	HL01 instance 7 user specified effective bulk modulus [bar]
1	HL01 instance 7 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 7 pressure at port 1 [bar]
5.0000E+00	HL03 instance 3 diameter of pipe [mm]
6.0000E-02	HL03 instance 3 pipe length [m]
1.0000E-05	HL03 instance 3 relative roughness [null]
0.0000E+00	HL03 instance 3 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL03 instance 3 wall thickness [mm]
2.0600E+06	HL03 instance 3 Young's modulus for material [bar]
1.7000E+04	HL03 instance 3 user specified effective bulk modulus [bar]
1	HL03 instance 3 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL03 instance 3 pressure at port 1 [bar]
5.0000E+01	HL03 instance 3 pressure at port 2 [bar]

A 3.2.3 Model: Isolated WSE pilot valve

This model is discussed in paragraph 3.7.

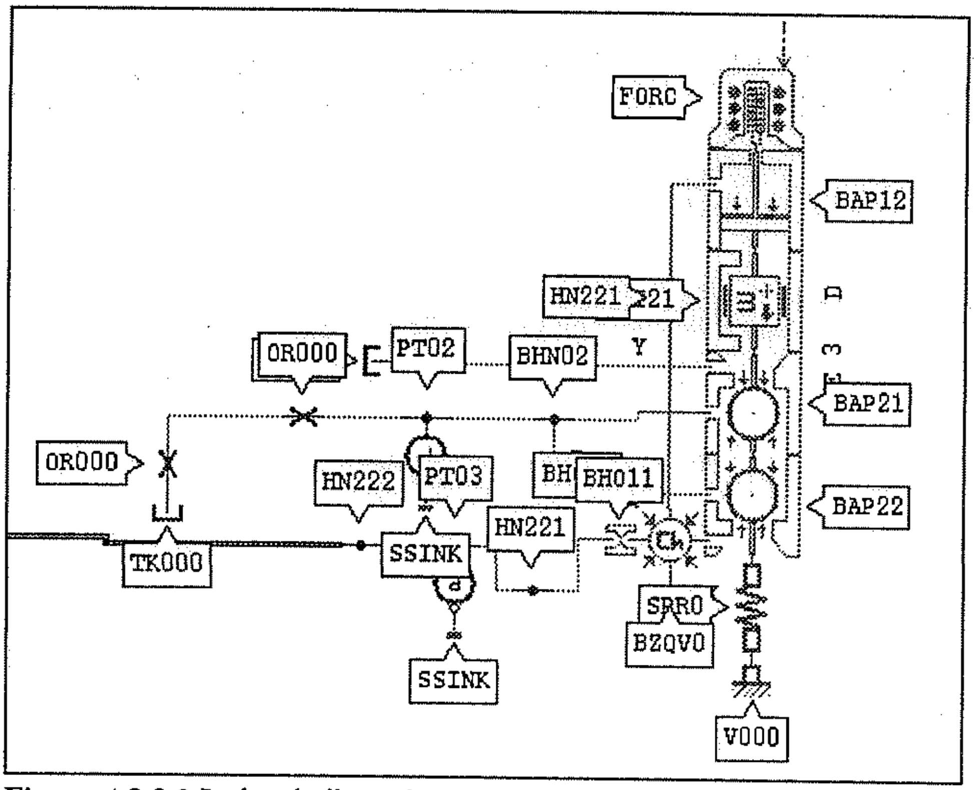

Figure A3.2.2 Isolated pilot valve model in AMESim

Parameters pertaining to the isolated pilot valve model:

-1.0000E-03	SPR0 instance 1 initial spring displacement [m]
2.7089E+04	SPR0 instance 1 spring rate [N/m]
0.0000E+00	SPR0 instance 1 displacement giving zero spring force [m]
0.0000E+00	SPR0 instance 1 force at port 2 [N]
3.0000E+00	BAP22 instance 1 seat diameter [mm]
4.0000E+00	BAP22 instance 1 ball diameter [mm]
4.0000E+00	BAP22 instance 1 rod diameter (opposite to seat) [mm]
0.0000E+00	BAP22 instance 1 rod diameter (seat side) [mm]
0.0000E+00	BAP22 instance 1 jet forces coefficient [null]
6.0000E-01	BAP22 instance 1 maximum flow coefficient [null]
1.0000E+03	BAP22 instance 1 critical flow number [null]
9.0000E-01	BAP22 instance 1 opening (underlap) corresponding to zero displacement [mm]
0.0000E+00	BAP22 instance 1 opening for minimum area [mm]
9.0000E-01	BAP22 instance 1 opening for maximum area [mm]
4.0000E-01	BAP22 instance 1 volume at port 1 corresponding to zero lift [cm**3]
8.0000E-01	BAP22 instance 1 volume at port 2 corresponding to zero lift [cm**3]
2.8000E+00	BAP21 instance 1 seat diameter [mm]
4.0000E+00	BAP21 instance 1 ball diameter [mm]
4.0000E+00	BAP21 instance 1 rod diameter (opposite to seat) [mm]
1.5000E+00	BAP21 instance 1 rod diameter (seat side) [mm]
0.0000E+00	BAP21 instance 1 jet force coefficient [null]
4.3000E-01	BAP21 instance 1 maximum flow coefficient [null]
1.0000E+02	BAP21 instance 1 critical flow number [null]
0.0000E+00	BAP21 instance 1 opening (underlap) corresponding to zero displacement [mm]
0.0000E+00	BAP21 instance 1 opening for minimum area [mm]
9.0000E-01	BAP21 instance 1 opening for maximum area [mm]
4.0000E-01	BAP21 instance 1 volume at port 1 corresponding to zero lift [cm**3]
8.0000E-01	BAP21 instance 1 volume at port 2 corresponding to zero lift [cm**3]
2.0000E-02	BAI21 instance 1 mass [kg]

0.0000E+00	BAI21 instance 1 stiction friction force (static) [N]
0.0000E+00	BAI21 instance 1 Coulomb friction force (dynamic) [N]
2.0000E+02	BAI21 instance 1 viscous friction [N/(m/s)]
0.0000E+00	BAI21 instance 1 windage friction [N/(m/s)**2]
1.0000E-06	BAI21 instance 1 stick velocity threshold [m/s]
1.0000E-03	BAI21 instance 1 Stribeck time constant [s]
0.0000E+00	BAI21 instance 1 lower displacement limit [m]
9.0000E-04	BAI21 instance 1 higher displacement limit [m]
0.0000E+00	BAI21 instance 1 inclination (+90 port 1 lowest -90 port 1 highest) [degree]
0.0000E+00	BAI21 instance 1 velocity port 2 [m/s]
5.0000E-04	BAI21 instance 1 displacement port 2 [m]
2.8000E+00	BAP12 instance 1 piston diameter [mm]
0.0000E+00	BAP12 instance 1 rod diameter [mm]
2.0000E+00	BAP12 instance 1 chamber length at zero displacement [mm]
3.0000E-03	CONS0 instance 1 constant value [null]
x/y	FXY0 instance 1 expression for output in terms of x and y
exp(x)	FX00 instance 1 expression in terms of the input x
4.0000E-02	CONS0 instance 2 constant value [null]
x/y	FXY0 instance 2 expression for output in terms of x and y
exp(x)	FX00 instance 2 expression in terms of the input x
2.0000E+02	CONS0 instance 3 constant value [null]
2.5000E-02	CONS0 instance 4 constant value [null]
3.0000E+00	CONS0 instance 5 constant value [null]
1.0000E+00	CONS0 instance 6 constant value [null]
2.3000E-02	CONS0 instance 7 constant value [null]
0.0000E+00	TK000 instance 1 tank pressure [bar]
0.0000E+00	V000 instance 1 linear velocity (always zero) [m/s]
0.0000E+00	HN221 instance 1 volume port 1 [cm**3]
0.0000E+00	HN222 instance 1 volume port 2 [cm**3]
1.0000E+00	OR000 instance 1 characteristic flow rate [L/min]
1.0000E+00	OR000 instance 1 corresponding pressure drop [bar]
1.0000E+01	OR000 instance 1 equivalent orifice diameter [mm]
7.0000E-01	OR000 instance 1 maximum flow coefficient [null]
1.0000E+03	OR000 instance 1 critical flow number (laminar -> turbulent) [null]
1	OR000 instance 1 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	Q000 instance 1 flow rate (always zero) [L/min]
0.0000E+00	Q000 instance 2 flow rate (always zero) [L/min]
0.0000E+00	QS00 instance 1 time at which duty cycle starts [s]
1.2000E+01	QS00 instance 1 .flow rate at start of stage 1 [L/min]
1.2000E+01	QS00 instance 1 .flow rate at end of stage 1 [L/min]
3.0000E+01	QS00 instance 1 duration of stage 1 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 2 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 2 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 2 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 3 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 3 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 3 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 4 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 4 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 4 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 5 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 5 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 5 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 6 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 6 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 6 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 7 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 7 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 7 [s]
0.0000E+00	QS00 instance 1 .flow rate at start of stage 8 [L/min]
0.0000E+00	QS00 instance 1 .flow rate at end of stage 8 [L/min]
1.0000E+06	QS00 instance 1 duration of stage 8 [s]
0.0000E+00	TK000 instance 2 tank pressure [bar]
1.0000E+00	OR000 instance 2 characteristic flow rate [L/min]
1.0000E+00	OR000 instance 2 corresponding pressure drop [bar]
3.0000E+00	OR000 instance 2 equivalent orifice diameter [mm]
7.0000E-01	OR000 instance 2 maximum flow coefficient [null]
4.0000E+02	OR000 instance 2 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 2 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	PT02 instance 1 offset to be subtracted from pressure [bar]
1.0000E+00	PT02 instance 1 gain for signal output [1/bar]

1.0000E+00	OR000 instance 3 characteristic flow rate [L/min]
1.0000E+00	OR000 instance 3 corresponding pressure drop [bar]
5.0000E+00	OR000 instance 3 equivalent orifice diameter [mm]
5.4000E-01	OR000 instance 3 maximum flow coefficient [null]
2.0000E+03	OR000 instance 3 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 3 1 for pressure drop/flow rate pair 2 for orifice diameter
1.0760E+02	RV00 instance 1 relief valve cracking pressure [bar]
1.0000E+04	RV00 instance 1 relief valve flow rate pressure gradient [L/min/bar]
0.0000E+00	TK000 instance 3 tank pressure [bar]
9.0000E+01	OR000 instance 4 characteristic flow rate [L/min]
5.0000E+00	OR000 instance 4 corresponding pressure drop [bar]
6.0000E+00	OR000 instance 4 equivalent orifice diameter [mm]
5.0000E-01	OR000 instance 4 maximum flow coefficient [null]
4.0000E+02	OR000 instance 4 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 4 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	HN222 instance 2 volume port 2 [cm**3]
0.0000E+00	PT03 instance 1 offset to be subtracted from pressure [bar]
1.0000E+00	PT03 instance 1 gain for signal output [1/bar]
0.0000E+00	HN221 instance 2 volume port 1 [cm**3]
0.0000E+00	HN221 instance 3 volume port 1 [cm**3]
5.0000E-01	BHC11 instance 1 dead volume [cm**3]
5.0000E+01	BHC11 instance 1 pressure port 1 [bar]
0.0000E+00	BZQV0 instance 1 zero flow rate [L/min]
0.0000E+00	BZQV0 instance 1 zero volume [cm**3]
1.0000E+00	BHO11 instance 1 characteristic flow rate [L/min]
1.0000E+00	BHO11 instance 1 corresponding pressure drop [bar]
3.0000E+00	BHO11 instance 1 equivalent orifice diameter [mm]
4.0000E-01	BHO11 instance 1 maximum flow coefficient [null]
2.0000E+02	BHO11 instance 1 critical flow number (laminar -> turbulent) [null]
2	BHO11 instance 1 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	BHO11 instance 1 zero volume source [cm**3]
0.0000E+00	BHO11 instance 1 zero volume source [cm**3]
2.0000E+01	HL000 instance 1 diameter of pipe [mm]
6.0000E-02	HL000 instance 1 pipe length [m]
0.0000E+00	HL000 instance 1 wall thickness [mm]
2.0600E+06	HL000 instance 1 Young's modulus for material [bar]
1.7000E+04	HL000 instance 1 user specified effective bulk modulus [bar]
1	HL000 instance 1 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL000 instance 1 pressure at port 1 [bar]
2.4000E+01	HL06 instance 1 diameter of pipe [mm]
5.2000E+00	HL06 instance 1 pipe length [m]
1.0000E-05	HL06 instance 1 relative roughness [null]
0.0000E+00	HL06 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
3.0000E+00	HL06 instance 1 wall thickness [mm]
2.0600E+06	HL06 instance 1 Young's modulus for material [bar]
1.7000E+04	HL06 instance 1 user specified effective bulk modulus [bar]
1	HL06 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL06 instance 1 pressure at port 1 [bar]
0.0000E+00	HL06 instance 1 pressure at port 2 [bar]
0.0000E+00	HL06 instance 1 flow rate at centre of pipe [L/min]
2.8000E+01	HL01 instance 1 diameter of pipe [mm]
1.0000E+00	HL01 instance 1 pipe length [m]
1.0000E-05	HL01 instance 1 relative roughness [null]
0.0000E+00	HL01 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL01 instance 1 wall thickness [mm]
1.0000E+04	HL01 instance 1 Young's modulus for material [bar]
1.7000E+04	HL01 instance 1 user specified effective bulk modulus [bar]
1	HL01 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 1 pressure at port 1 [bar]
8.0000E+01	HL03 instance 1 diameter of pipe [mm]
3.0000E-01	HL03 instance 1 pipe length [m]
1.0000E-05	HL03 instance 1 relative roughness [null]
0.0000E+00	HL03 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
1.0000E+01	HL03 instance 1 wall thickness [mm]
2.0600E+06	HL03 instance 1 Young's modulus for material [bar]
1.7000E+04	HL03 instance 1 user specified effective bulk modulus [bar]
1	HL03 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL03 instance 1 pressure at port 1 [bar]
0.0000E+00	HL03 instance 1 pressure at port 2 [bar]
2.3000E+01	HL04 instance 1 diameter of pipe [mm]
3.3000E+00	HL04 instance 1 pipe length [m]

1.0000E-05	HL04 instance 1 relative roughness [null]
0.0000E+00	HL04 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL04 instance 1 wall thickness [mm]
1.0000E+04	HL04 instance 1 Young's modulus for material [bar]
1.7000E+04	HL04 instance 1 user specified effective bulk modulus [bar]
1	HL04 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL04 instance 1 pressure at port 1 [bar]
0.0000E+00	HL04 instance 1 flow rate at port 2 [L/min]
5.0000E+00	HL01 instance 2 diameter of pipe [mm]
8.0000E-02	HL01 instance 2 pipe length [m]
1.0000E-05	HL01 instance 2 relative roughness [null]
0.0000E+00	HL01 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 2 wall thickness [mm]
2.0600E+06	HL01 instance 2 Young's modulus for material [bar]
1.7000E+04	HL01 instance 2 user specified effective bulk modulus [bar]
1	HL01 instance 2 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL01 instance 2 pressure at port 1 [bar]
5.0000E+00	HL01 instance 3 diameter of pipe [mm]
6.0000E-02	HL01 instance 3 pipe length [m]
1.0000E-05	HL01 instance 3 relative roughness [null]
0.0000E+00	HL01 instance 3 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 3 wall thickness [mm]
2.0600E+06	HL01 instance 3 Young's modulus for material [bar]
1.7000E+04	HL01 instance 3 user specified effective bulk modulus [bar]
1	HL01 instance 3 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL01 instance 3 pressure at port 1 [bar]
4.0000E+00	HL01 instance 4 diameter of pipe [mm]
8.0000E-02	HL01 instance 4 pipe length [m]
1.0000E-05	HL01 instance 4 relative roughness [null]
0.0000E+00	HL01 instance 4 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 4 wall thickness [mm]
2.0600E+06	HL01 instance 4 Young's modulus for material [bar]
1.7000E+04	HL01 instance 4 user specified effective bulk modulus [bar]
1	HL01 instance 4 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL01 instance 4 pressure at port 1 [bar]
6.0000E+00	HL03 instance 2 diameter of pipe [mm]
6.0000E-01	HL03 instance 2 pipe length [m]
1.0000E-05	HL03 instance 2 relative roughness [null]
0.0000E+00	HL03 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
4.0000E+00	HL03 instance 2 wall thickness [mm]
4.0000E+04	HL03 instance 2 Young's modulus for material [bar]
1.7000E+04	HL03 instance 2 user specified effective bulk modulus [bar]
1	HL03 instance 2 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL03 instance 2 pressure at port 1 [bar]
1.0000E+01	HL03 instance 2 pressure at port 2 [bar]
1.5000E+01	HL01 instance 5 diameter of pipe [mm]
6.0000E-01	HL01 instance 5 pipe length [m]
1.0000E-05	HL01 instance 5 relative roughness [null]
0.0000E+00	HL01 instance 5 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
2.5000E+00	HL01 instance 5 wall thickness [mm]
2.0600E+06	HL01 instance 5 Young's modulus for material [bar]
1.7000E+04	HL01 instance 5 user specified effective bulk modulus [bar]
1	HL01 instance 5 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 5 pressure at port 1 [bar]
2.8000E+01	HL02 instance 1 diameter of pipe [mm]
5.0000E-01	HL02 instance 1 pipe length [m]
1.0000E-05	HL02 instance 1 relative roughness [null]
0.0000E+00	HL02 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL02 instance 1 wall thickness [mm]
1.0000E+04	HL02 instance 1 Young's modulus for material [bar]
1.7000E+04	HL02 instance 1 user specified effective bulk modulus [bar]
1	HL02 instance 1 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL02 instance 1 pressure at mid-point [bar]
6.0000E+00	HL000 instance 2 diameter of pipe [mm]
6.0000E-01	HL000 instance 2 pipe length [m]
4.0000E+00	HL000 instance 2 wall thickness [mm]
1.0000E+04	HL000 instance 2 Young's modulus for material [bar]
1.7000E+04	HL000 instance 2 user specified effective bulk modulus [bar]
1	HL000 instance 2 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL000 instance 2 pressure at port 1 [bar]
2.5000E+01	HL000 instance 3 diameter of pipe [mm]

1.0000E+00	HL000 instance 3 pipe length [m]
1.0000E+01	HL000 instance 3 wall thickness [mm]
2.0600E+06	HL000 instance 3 Young's modulus for material [bar]
1.7000E+04	HL000 instance 3 user specified effective bulk modulus [bar]
1	HL000 instance 3 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL000 instance 3 pressure at port 1 [bar]
1.0000E+00	HL01 instance 6 diameter of pipe [mm]
3.0000E-02	HL01 instance 6 pipe length [m]
1.0000E-05	HL01 instance 6 relative roughness [null]
0.0000E+00	HL01 instance 6 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 6 wall thickness [mm]
2.0600E+06	HL01 instance 6 Young's modulus for material [bar]
1.7000E+04	HL01 instance 6 user specified effective bulk modulus [bar]
1	HL01 instance 6 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 6 pressure at port 1 [bar]
5.0000E+00	HL02 instance 2 diameter of pipe [mm]
5.0000E-02	HL02 instance 2 pipe length [m]
1.0000E-05	HL02 instance 2 relative roughness [null]
0.0000E+00	HL02 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
1.0000E+01	HL02 instance 2 wall thickness [mm]
2.0600E+06	HL02 instance 2 Young's modulus for material [bar]
1.7000E+04	HL02 instance 2 user specified effective bulk modulus [bar]
1	HL02 instance 2 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL02 instance 2 pressure at mid-point [bar]
3.0000E+00	HL01 instance 7 diameter of pipe [mm]
5.0000E-02	HL01 instance 7 pipe length [m]
1.0000E-05	HL01 instance 7 relative roughness [null]
0.0000E+00	HL01 instance 7 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 7 wall thickness [mm]
2.0600E+06	HL01 instance 7 Young's modulus for material [bar]
1.7000E+04	HL01 instance 7 user specified effective bulk modulus [bar]
1	HL01 instance 7 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 7 pressure at port 1 [bar]
5.0000E+00	HL03 instance 3 diameter of pipe [mm]
6.0000E-02	HL03 instance 3 pipe length [m]
1.0000E-05	HL03 instance 3 relative roughness [null]
0.0000E+00	HL03 instance 3 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL03 instance 3 wall thickness [mm]
2.0600E+06	HL03 instance 3 Young's modulus for material [bar]
1.7000E+04	HL03 instance 3 user specified effective bulk modulus [bar]
1	HL03 instance 3 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL03 instance 3 pressure at port 1 [bar]
5.0000E+01	HL03 instance 3 pressure at port 2 [bar]

A 3.2.4 Model: Valve system with damper (without test bench supply pipes)

This model is discussed in paragraph 3.8 and paragraph 3.9.

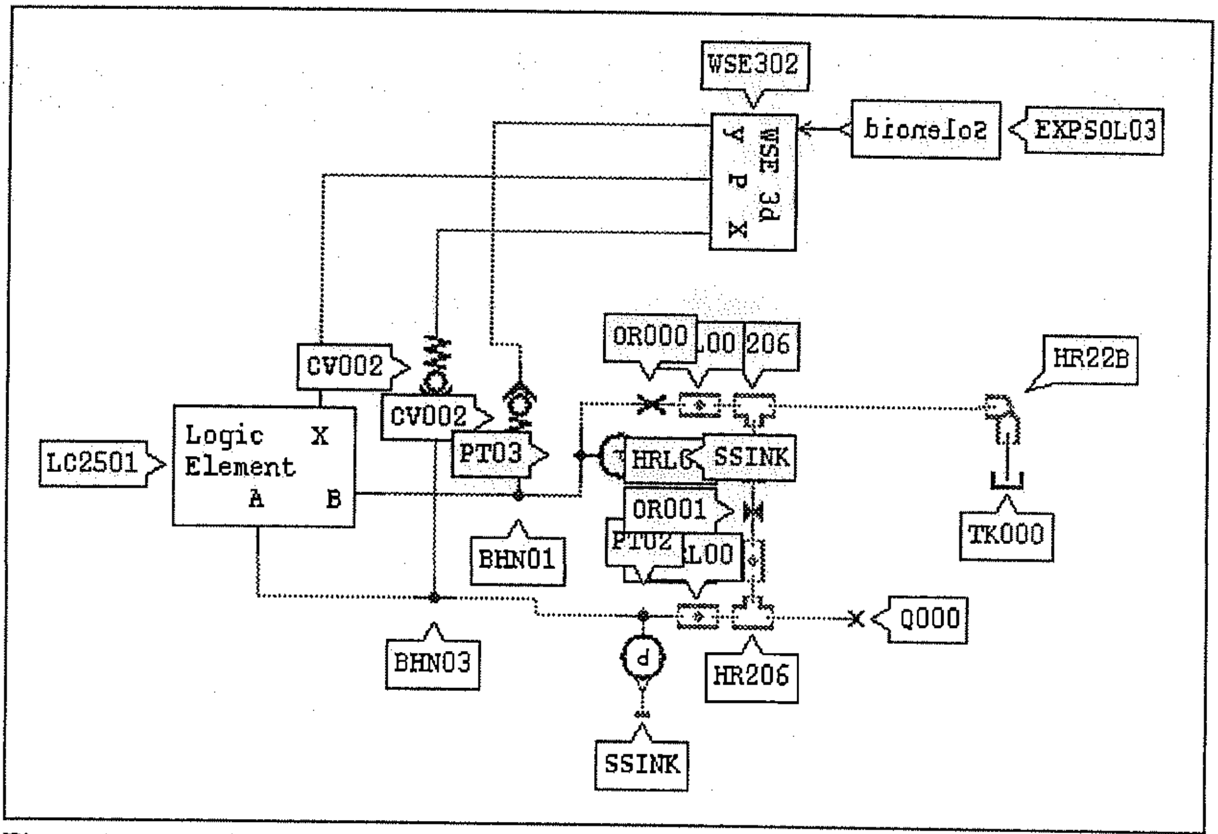

Figure A3.2.3 Valve system model without test bench supply line to reduce parameters displayed

Parameters pertaining to the valve system model: (without two supply lines)

0.0000E+00	Q000 instance 1 flow rate (always zero) [L/min]
x/2	FX00 instance 1 expression in terms of the input x
9.7000E+01	CONS0 instance 1 constant value [null]
2.2000E+01	HR206 instance 1 diameter at port 1 [mm]
2.2000E+01	HR206 instance 1 diameter at ports 2 and 3 [mm]
1.0000E-01	HR206 instance 1 friction factor in the main branch [null]
2.0000E+00	HR206 instance 1 friction factor side branch - main branch [null]
3.0000E+03	HR206 instance 1 critical Reynolds number [null]
0.0000E+00	HR206 instance 1 pressure at junction [bar]
2.2000E+01	HRL00 instance 1 diameter [mm]
1.0000E-01	HRL00 instance 1 length [m]
6.0000E+01	HRL00 instance 1 total pressure [bar]
2.2000E+01	HRL00 instance 2 diameter [mm]
1.0000E-01	HRL00 instance 2 length [m]
6.0000E+01	HRL00 instance 2 total pressure [bar]
2.2000E+01	HR206 instance 2 diameter at port 1 [mm]
2.2000E+01	HR206 instance 2 diameter at ports 2 and 3 [mm]
5.0000E-02	HR206 instance 2 friction factor in the main branch [null]
1.5000E+00	HR206 instance 2 friction factor side branch - main branch [null]
3.0000E+03	HR206 instance 2 critical Reynolds number [null]
0.0000E+00	HR206 instance 2 pressure at junction [bar]
2.2000E+01	HRL00 instance 3 diameter [mm]
1.0000E-01	HRL00 instance 3 length [m]
6.0000E+01	HRL00 instance 3 total pressure [bar]
0.0000E+00	PT02 instance 1 offset to be subtracted from pressure [bar]
1.0000E+00	PT02 instance 1 gain for signal output [1/bar]
2.2000E+01	HRL00 instance 4 diameter [mm]

1.0000E-01	HRL00 instance 4 length [m]
6.0000E+01	HRL00 instance 4 total pressure [bar]
1.8000E+01	HR22B instance 1 diameter [mm]
1.2000E+00	HR22B instance 1 friction factor for flow ports 1 -> 2 [null]
1.2000E+00	HR22B instance 1 friction factor for flow ports 2 -> 1 [null]
5.0000E+02	HR22B instance 1 critical Reynolds number [null]
0.0000E+00	HR22B instance 1 hysteresis [bar]
0.0000E+00	TK000 instance 1 tank pressure [bar]
1.0000E+00	OR001 instance 1 flow rate gain [null]
1.0000E+00	OR001 instance 1 pressure gain [null]
damperexpcurve.dat	OR001 instance 1 filename or expression for flow rate characteristic q=f(p) q in L/min
0.0000E+00	CV002 instance 1 check valve cracking pressure [bar]
3.5000E+00	CV002 instance 1 check valve flow rate pressure gradient [L/min/bar]
1.2000E+01	CV002 instance 1 nominal flow rate valve fully open [L/min]
2.0000E+00	CV002 instance 1 corresponding pressure drop [bar]
1.0000E-04	CV002 instance 1 hysteresis for opening/closing [bar]
1.5000E+00	CV002 instance 2 check valve cracking pressure [bar]
3.5000E+00	CV002 instance 2 check valve flow rate pressure gradient [L/min/bar]
1.2000E+01	CV002 instance 2 nominal flow rate valve fully open [L/min]
2.0000E+00	CV002 instance 2 corresponding pressure drop [bar]
1.0000E-04	CV002 instance 2 hysteresis for opening/closing [bar]
1.0000E+00	OR000 instance 1 characteristic flow rate [L/min]
1.0000E+00	OR000 instance 1 corresponding pressure drop [bar]
5.0000E+01	OR000 instance 1 equivalent orifice diameter [mm]
4.0000E-01	OR000 instance 1 maximum flow coefficient [null]
8.0000E+02	OR000 instance 1 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 1 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	PT03 instance 1 offset to be subtracted from pressure [bar]
1.0000E+00	PT03 instance 1 gain for signal output [1/bar]
8.2330E-02	BAI21 instance 1 mass [kg]
0.0000E+00	BAI21 instance 1 stiction friction force (static) [N]
0.0000E+00	BAI21 instance 1 Coulomb friction force (dynamic) [N]
1.0000E+03	BAI21 instance 1 viscous friction [N/(m/s)]
1.0000E+03	BAI21 instance 1 windage friction [N/(m/s)**2]
1.0000E-06	BAI21 instance 1 stick velocity threshold [m/s]
1.0000E-03	BAI21 instance 1 Stribeck time constant [s]
0.0000E+00	BAI21 instance 1 lower displacement limit [m]
8.0000E-03	BAI21 instance 1 higher displacement limit [m]
0.0000E+00	BAI21 instance 1 inclination (+90 port 1 lowest -90 port 1 highest) [degree]
0.0000E+00	BAI21 instance 1 velocity port 2 [m/s]
8.0000E-03	BAI21 instance 1 displacement port 2 [m]
2.5000E+01	BAP15 instance 1 piston diameter [mm]
0.0000E+00	BAP15 instance 1 rod diameter [mm]
3.5000E+00	BAP15 instance 1 spring stiffness [N/mm]
6.0000E+01	BAP15 instance 1 spring force at zero displacement [N]
4.4000E+01	BAP15 instance 1 chamber length at zero displacement [mm]
2.1000E+01	BAP26 instance 1 seat diameter [mm]
0.0000E+00	BAP26 instance 1 rod diameter (seat side) [mm]
2.5000E+01	BAP26 instance 1 diameter of poppet [mm]
4.5000E+01	BAP26 instance 1 poppet half angle [degree]
8.0000E-01	BAP26 instance 1 maximum flow coefficient [null]
2.0000E+03	BAP26 instance 1 critical flow number [null]
0.0000E+00	BAP26 instance 1 opening for minimum area [mm]
8.0000E+00	BAP26 instance 1 opening for maximum area [mm]
1.0000E+00	BAP26 instance 1 jet forces coefficient [null]
0.0000E+00	BAP26 instance 1 lift (underlap) corresponding to zero displacement [mm]
1.0000E+00	BAP26 instance 1 volume at port 1 corresponding to zero lift [cm**3]
2.0000E+00	BAP26 instance 1 volume at port 2 corresponding to zero lift [cm**3]
0.0000E+00	F000 instance 1 force (always zero) [N]
0.0000E+00	F000 instance 2 force (always zero) [N]
0.0000E+00	HN221 instance 1 volume port 1 [cm**3]
0.0000E+00	HN222 instance 1 volume port 2 [cm**3]
1.0000E+00	OR000 instance 2 characteristic flow rate [L/min]
1.0000E+00	OR000 instance 2 corresponding pressure drop [bar]
2.0000E+01	OR000 instance 2 equivalent orifice diameter [mm]
7.0000E-01	OR000 instance 2 maximum flow coefficient [null]
1.0000E+03	OR000 instance 2 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 2 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	Q000 instance 2 flow rate (always zero) [L/min]
9.0000E+01	OR000 instance 3 characteristic flow rate [L/min]

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5.0000E+00	OR000 instance 3 corresponding pressure drop [bar]
2.0000E+01	OR000 instance 3 equivalent orifice diameter [mm]
5.0000E-01	OR000 instance 3 maximum flow coefficient [null]
1.0000E+03	OR000 instance 3 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 3 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	HN222 instance 2 volume port 2 [cm**3]
0.0000E+00	HN222 instance 3 volume port 2 [cm**3]
0.0000E+00	HN221 instance 2 volume port 1 [cm**3]
0.0000E+00	HN222 instance 4 volume port 2 [cm**3]
1.0000E+00	OR000 instance 4 characteristic flow rate [L/min]
1.0000E+00	OR000 instance 4 corresponding pressure drop [bar]
2.0000E+01	OR000 instance 4 equivalent orifice diameter [mm]
7.0000E-01	OR000 instance 4 maximum flow coefficient [null]
1.0000E+03	OR000 instance 4 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 4 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	Q000 instance 3 flow rate (always zero) [L/min]
9.0000E+01	OR000 instance 5 characteristic flow rate [L/min]
5.0000E+00	OR000 instance 5 corresponding pressure drop [bar]
2.0000E+01	OR000 instance 5 equivalent orifice diameter [mm]
5.0000E-01	OR000 instance 5 maximum flow coefficient [null]
1.0000E+03	OR000 instance 5 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 5 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	HN222 instance 5 volume port 2 [cm**3]
0.0000E+00	HN222 instance 6 volume port 2 [cm**3]
-1.0000E-03	SPR0 instance 1 initial spring displacement [m]
2.7089E+04	SPR0 instance 1 spring rate [N/m]
0.0000E+00	SPR0 instance 1 displacement giving zero spring force [m]
0.0000E+00	SPR0 instance 1 force at port 2 [N]
3.0000E+00	BAP22 instance 1 seat diameter [mm]
4.0000E+00	BAP22 instance 1 ball diameter [mm]
4.0000E+00	BAP22 instance 1 rod diameter (opposite to seat) [mm]
0.0000E+00	BAP22 instance 1 rod diameter (seat side) [mm]
0.0000E+00	BAP22 instance 1 jet forces coefficient [null]
6.0000E-01	BAP22 instance 1 maximum flow coefficient [null]
1.0000E+03	BAP22 instance 1 critical flow number [null]
9.0000E-01	BAP22 instance 1 opening (underlap) corresponding to zero displacement [mm]
0.0000E+00	BAP22 instance 1 opening for minimum area [mm]
9.0000E-01	BAP22 instance 1 opening for maximum area [mm]
4.0000E-01	BAP22 instance 1 volume at port 1 corresponding to zero lift [cm**3]
8.0000E-01	BAP22 instance 1 volume at port 2 corresponding to zero lift [cm**3]
2.8000E+00	BAP21 instance 1 seat diameter [mm]
4.0000E+00	BAP21 instance 1 ball diameter [mm]
4.0000E+00	BAP21 instance 1 rod diameter (opposite to seat) [mm]
1.5000E+00	BAP21 instance 1 rod diameter (seat side) [mm]
0.0000E+00	BAP21 instance 1 jet force coefficient [null]
4.3000E-01	BAP21 instance 1 maximum flow coefficient [null]
1.0000E+02	BAP21 instance 1 critical flow number [null]
0.0000E+00	BAP21 instance 1 opening (underlap) corresponding to zero displacement [mm]
0.0000E+00	BAP21 instance 1 opening for minimum area [mm]
9.0000E-01	BAP21 instance 1 opening for maximum area [mm]
4.0000E-01	BAP21 instance 1 volume at port 1 corresponding to zero lift [cm**3]
8.0000E-01	BAP21 instance 1 volume at port 2 corresponding to zero lift [cm**3]
2.0000E-02	BAI21 instance 2 mass [kg]
0.0000E+00	BAI21 instance 2 stiction friction force (static) [N]
0.0000E+00	BAI21 instance 2 Coulomb friction force (dynamic) [N]
2.0000E+02	BAI21 instance 2 viscous friction [N/(m/s)]
0.0000E+00	BAI21 instance 2 windage friction [N/(m/s)**2]
1.0000E-06	BAI21 instance 2 stick velocity threshold [m/s]
1.0000E-03	BAI21 instance 2 Stribeck time constant [s]
0.0000E+00	BAI21 instance 2 lower displacement limit [m]
9.0000E-04	BAI21 instance 2 higher displacement limit [m]
0.0000E+00	BAI21 instance 2 inclination (+90 port 1 lowest -90 port 1 highest) [degree]
0.0000E+00	BAI21 instance 2 velocity port 2 [m/s]
5.0000E-04	BAI21 instance 2 displacement port 2 [m]
2.8000E+00	BAP12 instance 1 piston diameter [mm]
0.0000E+00	BAP12 instance 1 rod diameter [mm]
2.0000E+00	BAP12 instance 1 chamber length at zero displacement [mm]
0.0000E+00	V000 instance 1 linear velocity (always zero) [m/s]
0.0000E+00	PT02 instance 2 offset to be subtracted from pressure [bar]
1.0000E+00	PT02 instance 2 gain for signal output [1/bar]
1.0000E+00	OR000 instance 6 characteristic flow rate [L/min]

1.0000E+00	OR000 instance 6 corresponding pressure drop [bar]
5.0000E+00	OR000 instance 6 equivalent orifice diameter [mm]
1.0000E+00	OR000 instance 6 maximum flow coefficient [null]
2.0000E+03	OR000 instance 6 critical flow number (laminar -> turbulent) [null]
2	OR000 instance 6 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	HN222 instance 7 volume port 2 [cm**3]
0.0000E+00	PT03 instance 2 offset to be subtracted from pressure [bar]
1.0000E+00	PT03 instance 2 gain for signal output [1/bar]
0.0000E+00	HN221 instance 3 volume port 1 [cm**3]
0.0000E+00	HN221 instance 4 volume port 1 [cm**3]
5.0000E-01	BHC11 instance 1 dead volume [cm**3]
5.0000E+01	BHC11 instance 1 pressure port 1 [bar]
0.0000E+00	BZQV0 instance 1 zero flow rate [L/min]
0.0000E+00	BZQV0 instance 1 zero volume [cm**3]
1.0000E+00	BHO11 instance 1 characteristic flow rate [L/min]
1.0000E+00	BHO11 instance 1 corresponding pressure drop [bar]
3.0000E+00	BHO11 instance 1 equivalent orifice diameter [mm]
4.0000E-01	BHO11 instance 1 maximum flow coefficient [null]
2.0000E+02	BHO11 instance 1 critical flow number (laminar -> turbulent) [null]
2	BHO11 instance 1 1 for pressure drop/flow rate pair 2 for orifice diameter
0.0000E+00	BHO11 instance 1 zero volume source [cm**3]
0.0000E+00	BHO11 instance 1 zero volume source [cm**3]
3.0000E-03	CONS0 instance 2 constant value [null]
x/y	FXY0 instance 1 expression for output in terms of x and y
exp(x)	FX00 instance 2 expression in terms of the input x
4.0000E-02	CONS0 instance 3 constant value [null]
x/y	FXY0 instance 2 expression for output in terms of x and y
exp(x)	FX00 instance 3 expression in terms of the input x
2.0000E+02	CONS0 instance 4 constant value [null]
2.5000E-02	CONS0 instance 5 constant value [null]
1.0000E+00	CONS0 instance 6 constant value [null]
5.0000E-01	CONS0 instance 7 constant value [null]
2.3000E-02	CONS0 instance 8 constant value [null]
2.5000E+01	HL000 instance 1 diameter of pipe [mm]
3.0000E-01	HL000 instance 1 pipe length [m]
3.0000E+00	HL000 instance 1 wall thickness [mm]
2.0600E+06	HL000 instance 1 Young's modulus for material [bar]
1.7000E+04	HL000 instance 1 user specified effective bulk modulus [bar]
1	HL000 instance 1 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL000 instance 1 pressure at port 1 [bar]
2.5000E+01	HL000 instance 2 diameter of pipe [mm]
1.0000E-02	HL000 instance 2 pipe length [m]
0.0000E+00	HL000 instance 2 wall thickness [mm]
2.0600E+06	HL000 instance 2 Young's modulus for material [bar]
1.7000E+04	HL000 instance 2 user specified effective bulk modulus [bar]
1	HL000 instance 2 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL000 instance 2 pressure at port 1 [bar]
1.5000E+01	HL02 instance 1 diameter of pipe [mm]
1.0000E-01	HL02 instance 1 pipe length [m]
1.0000E-05	HL02 instance 1 relative roughness [null]
0.0000E+00	HL02 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL02 instance 1 wall thickness [mm]
2.0600E+06	HL02 instance 1 Young's modulus for material [bar]
1.7000E+04	HL02 instance 1 user specified effective bulk modulus [bar]
1	HL02 instance 1 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL02 instance 1 pressure at mid-point [bar]
2.5000E+01	HL000 instance 3 diameter of pipe [mm]
3.0000E-01	HL000 instance 3 pipe length [m]
3.0000E+00	HL000 instance 3 wall thickness [mm]
2.0600E+06	HL000 instance 3 Young's modulus for material [bar]
1.7000E+04	HL000 instance 3 user specified effective bulk modulus [bar]
1	HL000 instance 3 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL000 instance 3 pressure at port 1 [bar]
2.5000E+01	HL000 instance 4 diameter of pipe [mm]
3.0000E-02	HL000 instance 4 pipe length [m]
0.0000E+00	HL000 instance 4 wall thickness [mm]
2.0600E+06	HL000 instance 4 Young's modulus for material [bar]
1.7000E+04	HL000 instance 4 user specified effective bulk modulus [bar]
1	HL000 instance 4 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL000 instance 4 pressure at port 1 [bar]
2.2000E+01	HL03 instance 1 diameter of pipe [mm]

5.0000E-01	HL03 instance 1 pipe length [m]
1.0000E-05	HL03 instance 1 relative roughness [null]
0.0000E+00	HL03 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL03 instance 1 wall thickness [mm]
1.0000E+04	HL03 instance 1 Young's modulus for material [bar]
1.7000E+04	HL03 instance 1 user specified effective bulk modulus [bar]
1	HL03 instance 1 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL03 instance 1 pressure at port 1 [bar]
6.0000E+01	HL03 instance 1 pressure at port 2 [bar]
2.0000E+01	HL06 instance 1 diameter of pipe [mm]
5.0000E-01	HL06 instance 1 pipe length [m]
1.0000E-05	HL06 instance 1 relative roughness [null]
0.0000E+00	HL06 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL06 instance 1 wall thickness [mm]
2.0000E+04	HL06 instance 1 Young's modulus for material [bar]
1.7000E+04	HL06 instance 1 user specified effective bulk modulus [bar]
1	HL06 instance 1 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL06 instance 1 pressure at port 1 [bar]
6.0000E+01	HL06 instance 1 pressure at port 2 [bar]
0.0000E+00	HL06 instance 1 flow rate at centre of pipe [L/min]
1.9000E+01	HL02 instance 2 diameter of pipe [mm]
1.6000E-01	HL02 instance 2 pipe length [m]
1.0000E-05	HL02 instance 2 relative roughness [null]
0.0000E+00	HL02 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL02 instance 2 wall thickness [mm]
2.0600E+06	HL02 instance 2 Young's modulus for material [bar]
1.7000E+04	HL02 instance 2 user specified effective bulk modulus [bar]
1	HL02 instance 2 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL02 instance 2 pressure at mid-point [bar]
3.0000E+00	HL000 instance 5 diameter of pipe [mm]
5.0000E-02	HL000 instance 5 pipe length [m]
0.0000E+00	HL000 instance 5 wall thickness [mm]
2.0600E+06	HL000 instance 5 Young's modulus for material [bar]
1.7000E+04	HL000 instance 5 user specified effective bulk modulus [bar]
1	HL000 instance 5 1 for calculated bulk modulus value 2 for user specified value
0.0000E+00	HL000 instance 5 pressure at port 1 [bar]
5.0000E+00	HL000 instance 6 diameter of pipe [mm]
4.0000E-02	HL000 instance 6 pipe length [m]
0.0000E+00	HL000 instance 6 wall thickness [mm]
2.0600E+06	HL000 instance 6 Young's modulus for material [bar]
1.7000E+04	HL000 instance 6 user specified effective bulk modulus [bar]
1	HL000 instance 6 1 for calculated bulk modulus value 2 for user specified value
0.0000E+00	HL000 instance 6 pressure at port 1 [bar]
3.0000E+00	HL000 instance 7 diameter of pipe [mm]
4.0000E-02	HL000 instance 7 pipe length [m]
0.0000E+00	HL000 instance 7 wall thickness [mm]
2.0600E+06	HL000 instance 7 Young's modulus for material [bar]
1.7000E+04	HL000 instance 7 user specified effective bulk modulus [bar]
1	HL000 instance 7 1 for calculated bulk modulus value 2 for user specified value
0.0000E+00	HL000 instance 7 pressure at port 1 [bar]
3.0000E+01	HL000 instance 8 diameter of pipe [mm]
4.0000E-02	HL000 instance 8 pipe length [m]
0.0000E+00	HL000 instance 8 wall thickness [mm]
2.0600E+06	HL000 instance 8 Young's modulus for material [bar]
1.7000E+04	HL000 instance 8 user specified effective bulk modulus [bar]
1	HL000 instance 8 1 for calculated bulk modulus value 2 for user specified value
0.0000E+00	HL000 instance 8 pressure at port 1 [bar]
2.4000E+01	HL06 instance 2 diameter of pipe [mm]
5.2000E+00	HL06 instance 2 pipe length [m]
1.0000E-05	HL06 instance 2 relative roughness [null]
0.0000E+00	HL06 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
3.0000E+00	HL06 instance 2 wall thickness [mm]
2.0600E+06	HL06 instance 2 Young's modulus for material [bar]
1.7000E+04	HL06 instance 2 user specified effective bulk modulus [bar]
1	HL06 instance 2 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL06 instance 2 pressure at port 1 [bar]
6.0000E+01	HL06 instance 2 pressure at port 2 [bar]
0.0000E+00	HL06 instance 2 flow rate at centre of pipe [L/min]
2.8000E+01	HL01 instance 1 diameter of pipe [mm]
1.0000E+00	HL01 instance 1 pipe length [m]
1.0000E-05	HL01 instance 1 relative roughness [null]

0.0000E+00	HL01 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL01 instance 1 wall thickness [mm]
1.0000E+04	HL01 instance 1 Young's modulus for material [bar]
1.7000E+04	HL01 instance 1 user specified effective bulk modulus [bar]
1	HL01 instance 1 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL01 instance 1 pressure at port 1 [bar]
8.0000E+01	HL03 instance 2 diameter of pipe [mm]
3.0000E-01	HL03 instance 2 pipe length [m]
1.0000E-05	HL03 instance 2 relative roughness [null]
0.0000E+00	HL03 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
1.0000E+01	HL03 instance 2 wall thickness [mm]
2.0600E+06	HL03 instance 2 Young's modulus for material [bar]
1.7000E+04	HL03 instance 2 user specified effective bulk modulus [bar]
1	HL03 instance 2 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL03 instance 2 pressure at port 1 [bar]
6.0000E+01	HL03 instance 2 pressure at port 2 [bar]
2.8000E+01	HL02 instance 3 diameter of pipe [mm]
5.0000E-01	HL02 instance 3 pipe length [m]
1.0000E-05	HL02 instance 3 relative roughness [null]
0.0000E+00	HL02 instance 3 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL02 instance 3 wall thickness [mm]
1.0000E+04	HL02 instance 3 Young's modulus for material [bar]
1.7000E+04	HL02 instance 3 user specified effective bulk modulus [bar]
1	HL02 instance 3 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL02 instance 3 pressure at mid-point [bar]
1.5000E+01	HL000 instance 9 diameter of pipe [mm]
1.0000E-01	HL000 instance 9 pipe length [m]
2.5000E+00	HL000 instance 9 wall thickness [mm]
2.0600E+06	HL000 instance 9 Young's modulus for material [bar]
1.7000E+04	HL000 instance 9 user specified effective bulk modulus [bar]
1	HL000 instance 9 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL000 instance 9 pressure at port 1 [bar]
1.5000E+01	HL01 instance 2 diameter of pipe [mm]
6.0000E-01	HL01 instance 2 pipe length [m]
1.0000E-05	HL01 instance 2 relative roughness [null]
0.0000E+00	HL01 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
2.5000E+00	HL01 instance 2 wall thickness [mm]
2.0600E+06	HL01 instance 2 Young's modulus for material [bar]
1.7000E+04	HL01 instance 2 user specified effective bulk modulus [bar]
1	HL01 instance 2 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL01 instance 2 pressure at port 1 [bar]
2.3000E+01	HL05 instance 1 diameter of pipe [mm]
3.3000E+00	HL05 instance 1 pipe length [m]
1.0000E-05	HL05 instance 1 relative roughness [null]
0.0000E+00	HL05 instance 1 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL05 instance 1 wall thickness [mm]
1.0000E+04	HL05 instance 1 Young's modulus for material [bar]
1.7000E+04	HL05 instance 1 user specified effective bulk modulus [bar]
1	HL05 instance 1 1 for calculated bulk modulus value 2 for user specified value
0.0000E+00	HL05 instance 1 flow rate at port 1 [L/min]
0.0000E+00	HL05 instance 1 flow rate at port 2 [L/min]
6.0000E+01	HL05 instance 1 pressure at mid-point [bar]
2.4000E+01	HL06 instance 3 diameter of pipe [mm]
5.2000E+00	HL06 instance 3 pipe length [m]
1.0000E-05	HL06 instance 3 relative roughness [null]
0.0000E+00	HL06 instance 3 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
3.0000E+00	HL06 instance 3 wall thickness [mm]
2.0600E+06	HL06 instance 3 Young's modulus for material [bar]
1.7000E+04	HL06 instance 3 user specified effective bulk modulus [bar]
1	HL06 instance 3 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL06 instance 3 pressure at port 1 [bar]
6.0000E+01	HL06 instance 3 pressure at port 2 [bar]
0.0000E+00	HL06 instance 3 flow rate at centre of pipe [L/min]
2.8000E+01	HL01 instance 3 diameter of pipe [mm]
1.0000E+00	HL01 instance 3 pipe length [m]
1.0000E-05	HL01 instance 3 relative roughness [null]
0.0000E+00	HL01 instance 3 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL01 instance 3 wall thickness [mm]
1.0000E+04	HL01 instance 3 Young's modulus for material [bar]
1.7000E+04	HL01 instance 3 user specified effective bulk modulus [bar]
1	HL01 instance 3 1 for calculated bulk modulus value 2 for user specified value

6.0000E+01	HL01 instance 3 pressure at port 1 [bar]
8.0000E+01	HL03 instance 3 diameter of pipe [mm]
5.0000E-01	HL03 instance 3 pipe length [m]
1.0000E-05	HL03 instance 3 relative roughness [null]
0.0000E+00	HL03 instance 3 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
1.0000E+01	HL03 instance 3 wall thickness [mm]
2.0600E+06	HL03 instance 3 Young's modulus for material [bar]
1.7000E+04	HL03 instance 3 user specified effective bulk modulus [bar]
1	HL03 instance 3 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL03 instance 3 pressure at port 1 [bar]
6.0000E+01	HL03 instance 3 pressure at port 2 [bar]
2.8000E+01	HL02 instance 4 diameter of pipe [mm]
5.0000E-01	HL02 instance 4 pipe length [m]
1.0000E-05	HL02 instance 4 relative roughness [null]
0.0000E+00	HL02 instance 4 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL02 instance 4 wall thickness [mm]
1.0000E+04	HL02 instance 4 Young's modulus for material [bar]
1.7000E+04	HL02 instance 4 user specified effective bulk modulus [bar]
1	HL02 instance 4 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL02 instance 4 pressure at mid-point [bar]
1.5000E+01	HL000 instance 10 diameter of pipe [mm]
1.0000E-01	HL000 instance 10 pipe length [m]
2.5000E+00	HL000 instance 10 wall thickness [mm]
2.0600E+06	HL000 instance 10 Young's modulus for material [bar]
1.7000E+04	HL000 instance 10 user specified effective bulk modulus [bar]
1	HL000 instance 10 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL000 instance 10 pressure at port 1 [bar]
1.5000E+01	HL01 instance 4 diameter of pipe [mm]
6.0000E-01	HL01 instance 4 pipe length [m]
1.0000E-05	HL01 instance 4 relative roughness [null]
0.0000E+00	HL01 instance 4 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
2.5000E+00	HL01 instance 4 wall thickness [mm]
2.0600E+06	HL01 instance 4 Young's modulus for material [bar]
1.7000E+04	HL01 instance 4 user specified effective bulk modulus [bar]
1	HL01 instance 4 1 for calculated bulk modulus value 2 for user specified value
6.0000E+01	HL01 instance 4 pressure at port 1 [bar]
2.3000E+01	HL05 instance 2 diameter of pipe [mm]
3.3000E+00	HL05 instance 2 pipe length [m]
1.0000E-05	HL05 instance 2 relative roughness [null]
0.0000E+00	HL05 instance 2 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
6.0000E+00	HL05 instance 2 wall thickness [mm]
1.0000E+04	HL05 instance 2 Young's modulus for material [bar]
1.7000E+04	HL05 instance 2 user specified effective bulk modulus [bar]
1	HL05 instance 2 1 for calculated bulk modulus value 2 for user specified value
0.0000E+00	HL05 instance 2 flow rate at port 1 [L/min]
0.0000E+00	HL05 instance 2 flow rate at port 2 [L/min]
6.0000E+01	HL05 instance 2 pressure at mid-point [bar]
2.0000E+01	HL000 instance 11 diameter of pipe [mm]
5.0000E-02	HL000 instance 11 pipe length [m]
0.0000E+00	HL000 instance 11 wall thickness [mm]
2.0600E+06	HL000 instance 11 Young's modulus for material [bar]
1.7000E+04	HL000 instance 11 user specified effective bulk modulus [bar]
1	HL000 instance 11 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL000 instance 11 pressure at port 1 [bar]
5.0000E+00	HL01 instance 5 diameter of pipe [mm]
5.0000E-02	HL01 instance 5 pipe length [m]
1.0000E-05	HL01 instance 5 relative roughness [null]
0.0000E+00	HL01 instance 5 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 5 wall thickness [mm]
2.0600E+06	HL01 instance 5 Young's modulus for material [bar]
1.7000E+04	HL01 instance 5 user specified effective bulk modulus [bar]
1	HL01 instance 5 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL01 instance 5 pressure at port 1 [bar]
5.0000E+00	HL01 instance 6 diameter of pipe [mm]
5.0000E-02	HL01 instance 6 pipe length [m]
1.0000E-05	HL01 instance 6 relative roughness [null]
0.0000E+00	HL01 instance 6 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 6 wall thickness [mm]
2.0600E+06	HL01 instance 6 Young's modulus for material [bar]
1.7000E+04	HL01 instance 6 user specified effective bulk modulus [bar]
1	HL01 instance 6 1 for calculated bulk modulus value 2 for user specified value

1.0000E+01	HL01 instance 6 pressure at port 1 [bar]
3.0000E+00	HL01 instance 7 diameter of pipe [mm]
5.0000E-02	HL01 instance 7 pipe length [m]
1.0000E-05	HL01 instance 7 relative roughness [null]
0.0000E+00	HL01 instance 7 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 7 wall thickness [mm]
2.0600E+06	HL01 instance 7 Young's modulus for material [bar]
1.7000E+04	HL01 instance 7 user specified effective bulk modulus [bar]
1	HL01 instance 7 1 for calculated bulk modulus value 2 for user specified value
1.0000E+01	HL01 instance 7 pressure at port 1 [bar]
1.0000E+00	HL01 instance 8 diameter of pipe [mm]
3.0000E-02	HL01 instance 8 pipe length [m]
1.0000E-05	HL01 instance 8 relative roughness [null]
0.0000E+00	HL01 instance 8 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 8 wall thickness [mm]
2.0600E+06	HL01 instance 8 Young's modulus for material [bar]
1.7000E+04	HL01 instance 8 user specified effective bulk modulus [bar]
1	HL01 instance 8 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 8 pressure at port 1 [bar]
5.0000E+00	HL02 instance 5 diameter of pipe [mm]
5.0000E-02	HL02 instance 5 pipe length [m]
1.0000E-05	HL02 instance 5 relative roughness [null]
0.0000E+00	HL02 instance 5 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
1.0000E+01	HL02 instance 5 wall thickness [mm]
2.0600E+06	HL02 instance 5 Young's modulus for material [bar]
1.7000E+04	HL02 instance 5 user specified effective bulk modulus [bar]
1	HL02 instance 5 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL02 instance 5 pressure at mid-point [bar]
3.0000E+00	HL01 instance 9 diameter of pipe [mm]
5.0000E-02	HL01 instance 9 pipe length [m]
1.0000E-05	HL01 instance 9 relative roughness [null]
0.0000E+00	HL01 instance 9 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL01 instance 9 wall thickness [mm]
2.0600E+06	HL01 instance 9 Young's modulus for material [bar]
1.7000E+04	HL01 instance 9 user specified effective bulk modulus [bar]
1	HL01 instance 9 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL01 instance 9 pressure at port 1 [bar]
5.0000E+00	HL03 instance 4 diameter of pipe [mm]
6.0000E-02	HL03 instance 4 pipe length [m]
1.0000E-05	HL03 instance 4 relative roughness [null]
0.0000E+00	HL03 instance 4 angle line makes with horizontal (+ve if port 2 above port 1) [degree]
0.0000E+00	HL03 instance 4 wall thickness [mm]
2.0600E+06	HL03 instance 4 Young's modulus for material [bar]
1.7000E+04	HL03 instance 4 user specified effective bulk modulus [bar]
1	HL03 instance 4 1 for calculated bulk modulus value 2 for user specified value
5.0000E+01	HL03 instance 4 pressure at port 1 [bar]
5.0000E+01	HL03 instance 4 pressure at port 2 [bar]

#

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Source Code: MATLAB A 3.3

The MATLAB source code is given for reference. Only some of the main model source code files are shown. Some support functions containing innovative MATLAB procedures are also included. In order to increase legibility, source code files are separated by a horizontal line, with the reference number indicated in a box.

Complete models: **PAGE**

Support functions:

Sensitivity functions:

COMPLETE MODELS:

A3.3.1

```
function ydot = ellmandeq(t,y);

% Simple nonlin DEQ
% Twee orifices in paralel oor 'n pomp
% states is Pa en Pb

% Neil Janse van Rensburg

global C;
% 1 Cd - orriface Cd
% 2 A orriface 1
% 3 A orriface 2
% 4 B Bulk modulus
% 5 rho
% 6 Vol pipe 1
% 7 Vol pipe 2

Pa=y(1);
Pb=y(2);

if t<=4
   Q1=0.9e-3;
else
   Q1=1e-3;
end

Q2=C(1)*C(2)*sqrt(2*abs(Pa-Pb)/C(5))*sign(Pa-Pb);
Q3=C(1)*C(3)*sqrt(2*abs(Pb)/C(5))*sign(Pb);

%disp([Q2 Q3])
%plot(t,Q2,'g.',t,Q3,'r.')
ydot=[C(4)*(Q1-Q2)/C(6)
   C(4)*(Q2-Q3)/C(7)];
```

A3.3.2

```
% Solver for ellmandeq
% Stiff example presented by Ellman
% solves 2 orifaces in series.

if 1      % THIS PART SOLVES THE MATLAB IMPLEMENTATION
clear
global C;

C=[0.6      % 1 Cd - orriface Cd
   (pi/4)*(8e-3)^2 % 2 A orriface 1
   (pi/4)*(7e-3)^2 % 3 A orriface 2
   10e9     % 4 B Bulk modulus
   900      % 5 rho
   10e-5       % 6 Vol pipe 1
   10e-2]; % 7 Vol pipe 2

initial=[1.084e6 0.684e6];
tspan=[0 10];

%figure(1)
%clf
%hold on
%[t Y]=ode45('ellmandeq',tspan,initial);
tic;
Fl=flops;
[t Y]=ode15s('ellmandeq',tspan,initial);
CPUt=toc;
Fl1=flops-Fl;

Pa=Y(:,1);
Pb=Y(:,2);
Q2=C(1)*C(2)*sqrt(2*abs(Pa-Pb)/C(5)).*sign(Pa-Pb);
Q3=C(1)*C(3)*sqrt(2*abs(Pb)/C(5)).*sign(Pb);
%plot(t,Q2,t,Q3)
%title('Flow through a stiff system')
%legend('Q2','Q3')

format bank
disp('          e-time     Flops          Flops/sek')
```

```
disp([CPUt F11 F11/CPUt])
format
end

if 1      % THIS PART PLOTS THE AMESim IMPLEMENTATION
% Ellman Example on AMESim

%capture('ellman','Asko-s example on AMESim','ellman')
load ellman.mat

%R Variable contents:
%1 - time [s]
%2 - HL000_1 pressure at port 1 [bar]
%3 - HL000_2 pressure at port 1 [bar]
%4 - OR000_1 flow rate at port 1 [L/min]
%5 - OR000_1 flow rate at port 1 [L/min]
%6 - OR000_2 flow rate at port 1 [L/min]
%7 - OR000_2 flow rate at port 1 [L/min]
%8 - QS00_1 user defined duty cycle flow rate [L/min]
%9 - TK00_1 tank pressure [bar]

ta=R(1,:);
P=R(2,:);
end

%Produce Output:
figure(1)
plot(t-4,Y(:,1)/1e6,'ro')
hold on
plot(ta-0.1,P/10,'b')
grid on
%title('solves 2 orifaces in series over a pump')
%xlabel('time')
%ylabel('Pressure    [MPa]')
legend('MATLAB','AMESim')
title('MATLAB and AMESim Solution of Ellman Stiffness Example')
xlabel('Time')
ylabel('Pressure    [MPa]')
```

A3.3.3

```
function [out1,out2,out3] = WSE3Draindeq(t,y,flag,C);
global V

% WSE model with state for pressure compensating chamber
% This model is a extension of wse3only with the added effect of
% a drain side state and orifice.

% Now includes the pressure compensating chamber with pressure Pch
% EVENT location at bumpstops
% 3-Way valve ONLY - taken from lc25wse3
% 3-way valve has magnetic circuit
% THE AME counterpart of this model used a flow source at 12LPM
% with a pressure limmiting relief valve.

% Neil Janse van Rensburg
%disp([t])  % Used to debug

% SYSTEM DEFINITION MATRIX IS C VARIABLE
% ==============================================================
% START OF DEQ
if nargin < 3 | isempty(flag)
   % Return dy/dt = f(t,y).

% External Inputs:
Qin=LPMIN(12); % converts l/min flow into m^3/s
PxSET=10.76e6;      %Relief valve cracking pressure setting
                    %   - Represent the test bench setting
% SYSTEM VARIABLES:
Px=y(1);
x3=y(2);
xx3=y(3);
psi=y(4);
Pch=y(5);   %Pressure compensating chamber pressure
Pp=y(6);
%psi=0;
disp(t)
%disp([PxSET Px])
```

```
%disp([Qin Qrelief])
%disp('----------------')

% ----------------------------------------------------------------
% CONTROL VALVE SECTION:
%Ptank=C.Assy(1);%Anyway =0  %Pressure at port P AFTER the orifice!
Py=C.Assy(2);  %Pressure in drain line from WSE

% SOLENOID FORCE SECTION:
Fsol=WSEDrainSolenoid(t,C);

% POPPET MASS DEQ: mxxx + cxx + kx = Fex
[xxx3,FexCNTRL]=Mass_DEQ((C.Cntr(1)-x3),xx3,C.Cntr(3),...
   C.Cntr(5),-C.Cntr(4),C.Cntr(17),...
   [Px*C.Cntr(7) -Pch*C.Cntr(16) -Fsol]);

% Bumpstop implementation:
if C.Cntr(6) == 1 & sign(xxx3) > 0  % het dus bo gestop
   C.Cntr(6)=0;      %Reset die flaggie
   %      disp('Control Valve Plak Bo')
   xxx3=0;
end
if C.Cntr(6) == -1 & sign(xxx3) < 0  % het dus onder gestop
   C.Cntr(6)=0;      %Reset die flaggie
   %      disp('Control Valve Plak onder')
   xxx3=0;
end
% trick om die versnelling te fix:
if x3 > C.Cntr(2) & x3 < C.Cntr(1)   % ie x is between the bumpstops
   xxx3=(FexCNTRL)/C.Cntr(3);
end
if x3 > C.Cntr(1)
   x3=C.Cntr(1);
end
if x3 < C.Cntr(2)
   x3=C.Cntr(2);
end

% A Orifice, Supply -> X   flow
%[Q] = orifice(deltaP,x,Cd,D,Retr,nu,rho) - SOME HELP IF YOU WANTED!
Qa = orifice((Px-Pp),x3,C.Cntr(10),C.Cntr(11),300,C.Fld(4),C.Fld(3));
% B Orifice, X -> Drain   flow
TOP3=C.Cntr(1);
BOT3=C.Cntr(2);
xb=(TOP3-BOT3)-x3;
Qb = orifice((Pp-Py),xb,C.Cntr(12),C.Cntr(13),C.Fld(2),C.Fld(4),C.Fld(3));
% C Orifice, Supply -> Drain   flow
xc=(TOP3-BOT3)*(x3-TOP3)*(x3-BOT3)/(-0.25*(TOP3^2+BOT3^2)+0.5*TOP3*BOT3);
Qc = orifice((Px-Py),xc,C.Cntr(14),C.Cntr(15),C.Fld(2),C.Fld(4),C.Fld(3));
% CH Orifice, Pressure compensating chamber
D=0.0008;
Qch = orifice((Px-Pch),D/4,0.1,D,300,C.Fld(4),C.Fld(3));
D2=0.007;
Qdrain=orifice((Pp-0),D2/4,0.1,D2,300,C.Fld(4),C.Fld(3));
Qrelief=IdealReliefValve(Px,0,PxSET,10/0.6);

% ----------------------------------------------------------------
% PIPE FLOW SUMMATION SECTION:
Qx=Qa; %-Qc;
Qcomp=Qin-Qx-Qrelief; %Supply flow to Control valve
%Qd=Qb-Qc;  %Drain flow from Control valve
Qp=Qa-Qb;
QdrainComp=Qp-Qdrain;
% Qch is to small to incorporate (assumption)

% ----------------------------------------------------------------
% PIPE VOLUME SECTION:
Vx = C.Assy(3);
Vch = 2.356e-9;    %VERY stiff!
Vdrain = C.Assy(4);

% COMPRESIBILITY
Pxx=C.Fld(1)*Qcomp/Vx;
Pchch=C.Fld(1)*Qch/Vch;
Ppp=C.Fld(1)*QdrainComp/Vdrain;
%Fix:
psipsi=0;
```

```
% ----------------------------------------------------------------------
out1=[Pxx       % Px'
    xx3         % x3'
   xxx3         % x3"
   psipsi       % Psi'
   Pchch        % Pch'
   Ppp];            % Pp'

% Provide graphical output
% ----------------------------------------------------------------------
L=(size(V.Out,1)+1);
%Pch=0; %fascilitate easy removal of Pch variable
V.Out(L,:)=[x3 Fsol FexCNTRL Px Qx Qrelief Qcomp psi Pch Pp QdrainComp];    %Used to return
values to calling function
V.t(L,:)=[t];

% END OF DEQ
% ======================================================================
else
  switch(flag)
  case 'events'          % Used only if odeset('Events','on').
     % Return event vectors VALUE, ISTERMINAL, and DIRECTION.
     % Locate zero-crossings
     TOP3=C.Cntr(1);
     BOT3=C.Cntr(2);
     x3=y(2);
     %*******************
 %    Sig=[0 0
 %     1 0.1
 %     0 0.4];
  Fsol=WSEDrainSolenoid(t,C);
% Fsol=Solenoid_Force_Lookup(t,Sig,24,0.02,20);
    %*******************
    %plot(t,(x3-TOP3)*1e5,'m*')    % Used to debug
     %plot(t,TOP3,'m-')    % Used to debug - shows TOP3 on graph
     %       [         3-WAY        ]
     out1 = [(x3-BOT3); (x3-TOP3)]'; % VALUE: ie ui aan watter een cross
     out2 = [1; 1]';     % ISTERMINAL: stop at zeros of height
     out3 = [-1; 1]'; % DIRECTION
  end
end
% ======================================================================
```

A3.3.4

```
function [ttout,yout,teout,yeout,ieout,V] = WSE3Drainsolve;

% WSE model with state for pressure compensating chamber
% This model is a extension of wse3only with the added effect of
% a drain side state and orifice.

clear
global V
format compact
format long %bank
% 3-Way valve ONLY
% 3-way valve has magnetic circuit
% Neil Janse van Rensburg

[C] = dimensionsWSEDrain;  % Function to calculate system variables
% V is a return variable for solved values;
V.Out=[];
V.t=[];
%V.Cont=[' x';'x3';'Vx';'Qx'];
tic; Fl=flops;

tstart = 0;
tfinal = 5.0;
% states is:
Px=10e6;  %CAUSED SOME NON-CLOSEURE.... Was set to 19e6
%      Px,  x3,  x3', psi', Pch, Pp
y0 = [Px; 8e-4; 0; 2e-8; Px; 1e6];  % Initial conditions
options = odeset('reltol',1e-1,'abstol',1e-5,'Events','on','refine',1,...
   'stats','off','BDF','on','MaxStep',1);
tout = tstart; yout = y0.';
teout = []; yeout = []; ieout = [];

while tstart < tfinal
```

```
    % Solve until the first terminal event.
    %[t,y,te,ye,ie] = 15s ode113('WSE3Onlydeq',[tstart tfinal],y0,options,C);
    [t,y,te,ye,ie] = ode15s('WSE3Draindeq',[tstart tfinal],y0,options,C);
    % Accumulate output.
%   disp([te ye])
   nt = length(t);
   tout = [tout; t(2:nt)];
   yout = [yout; y(2:nt,:)];
   teout = [teout; te];   % Events at tstart are never reported.
   yeout = [yeout; ye];
   ieout = [ieout; ie];
   % Reset the "initial" conditions after integrator halt
   y0(1) = y(nt,1);
   y0(2) = y(nt,2);
   y0(3) = y(nt,3);
   y0(4) = y(nt,4);
   y0(5) = y(nt,5);
   tstart = t(nt);
   % Set the new initial conditions according to type of zerocross.
   % SPIKE gives a graphical output when a zerocrossing occurs
   if length(ie) > 1
      warning(['More that one simultanious event at t='num2str(te')])
      disp([te ie])
%      pause
   end
%  ie
  if ~isempty(ie)
    %     for i = 1:length(te)
  i=length(te);

   if ie(i) == 1
      C.Cntr(6)=-1;
      y0(2) = C.Cntr(2);% 'BOT' value
      y0(3) = 0;   %eps; %???
      disp(['* CONTROL HIT THE BOTTOM *  t=' num2str(te')])
%     disp([te ie])
      spike=[te(i) te(i)
         -0.001 0.001];
      plot(spike(1,:),spike(2,:),'r')
%     pause
   end
   if ie(i) == 2
      C.Cntr(6)=1;
      y0(2) = C.Cntr(1);  % 'TOP' value
      y0(3) = 0;
      disp(['* CONTROL HIT THE TOP *  t=' num2str(te')])
%     disp([te ie])
      spike=[te(i) te(i)
         0.001 0.003];
      plot(spike(1,:),spike(2,:),'r')
%     pause
   end
%end
end
end  %End of integration loop*********************************************

if nargout > 0
  ttout = tout;
end
CPUt=toc;
Fll=flops-Fl;

format bank
disp('          e-time    Flops            Flops/sek')
disp([CPUt Fll Fll/CPUt])
format

if 1  %Provide Graphical Output
   disp('Working on Graphical Output')
   %1-x3 2-Fsol 3-FexCNTRL 4-Px 5-Qx 6-Qrelief 7-Qcomp 8-psi 9-Pch 10-Pp 11-QdrainComp
figure(1), clf, hold on
plot(V.t,V.Out(:,1),'r.')
title('Poppet displacement')
xlabel('Time    [s]')
ylabel('Displacement    [m]')
hold on
plot(ttout,yout(:,2),'bo')
```

```
hold off
yaxis([-0.0001 0.001])

figure(2), clf, hold on
plot(V.t,V.Out(:,3),'m.',V.t,V.Out(:,2),'bo')
title('FexCNTRL=m.   Fsol=bo')
yaxis([-800 800])
yline(0)

figure(3), clf, hold on
plot(V.t,m3ps(V.Out(:,6)),'bx',V.t,m3ps(V.Out(:,5)),...
    'r+',V.t,m3ps(V.Out(:,7)),'g*')
title('Qrelief=bx  Qx=r+  Qcomp=g*')
yline(12)
yaxis([-20 20])

figure(4), clf, hold on
plot(V.t,V.Out(:,4)/1e6,'b.',V.t,V.Out(:,10)/1e6,'m.')
hold on
plot(ttout,yout(:,1)/1e6,'b',ttout,yout(:,6)/1e6,'m')
hold off
title('Px=b. Pp=m.')
yaxis([-50 50])
ylabel('Pressure  [MPa]')

figure(5), clf, hold on
plot(V.t,V.Out(:,4)/1e6,'b.',V.t,V.Out(:,9)/1e6,'r.')
title('Px=b.  Pch=r.')
yaxis([0 50])
ylabel('Pressure  [MPa]')

figure(6), clf, hold on
plot(V.t,V.Out(:,1),'r.')
title('Poppet displacement')
xlabel('Time   [s]')
ylabel('Displacement    [m]')
hold on
plot(ttout,yout(:,2),'b')
hold off
yaxis([-0.0001 0.001])

disp('Graphical output is complete')
end
```

A3.3.5

```
function [C] = dimensionsWSEDrain;

% WSE model with state for pressure compensating chamber
% This model is a extension of wse3only with the added effect of
% a drain side state and orifice.

% Use to calculate and store the true dimensions of valve
% and valve blocks.

disp('The root dimension function WSEONLY was called')
disp('************************************************')
%TT=input('Continue O great master?')
% SCALE the dimensions:
% Length=10*length
S=1;

% MASS:
WSE_mass=0.020;  % WSE poppet  %AS used in AME
WSE_spring_mass=0.0009; %wse spring mass
%Volgens RAO, Mech.vibration:
WSE_Mass_eq=WSE_mass+(1/3)*WSE_spring_mass;

% VOLUMES:
% Klepblok;
Vdrain=(pi/4)*(0.025^2)*0.265; %2; %0.05; % Volume to rear of wse
Vb=Vdrain; %(pi/4)*(0.016^2)*0.050 + (pi/4)*(0.016^2)*0.260;
x=0; %Temporary poppet hoogte
Vx=(pi/4)*(0.025^2)*10.265; %Volume in front of WSE
 % L was 10m
%Damper:
Demp_Vol_A=0.001;  % F(x) !!!
```

```
Demp_Vol_B=0.001;  % F(x) !!!

% SPRING STIFFNESS:
% Shigley formula: p363
kwse=27089; %AS used in AME [N/m]
InitDispL=0.001;  % Initial Spring Displacement

% AREAS:
%Poppet;
Aa=189e-6;   %m^2  According to the catalog
Ab=426e-6;   %m^2
Ax=616e-6;   %m^2

%WSE Valve:
wseballdia=0.004;
wseseatdia=0.003;
Aswse=(pi/4)*(wseseatdia)^2;      % 7 As
Adwse=(pi/4)*(0.6*wseballdia)^2;      % 8 Ad
Axwse=(pi/4)*(0.7*wseballdia)^2;      % 9 Ax
ACompPiston=(pi/4)*(0.0028^2); %Compensating chamber piston dia.

%DAMPING:
cwse=2000; %0;
cLC25=200;

% MOVEMENTS:
Pop_max_x=0.008;    %m
WSE_max_x=0.0009;    %m

% CD:
% DIAMETERS:
% Poppet orifice:
Pop_orr_diam=0.0245;  %m
WSE_orr_diamA=0.002;          % 11 Diameter A
WSE_orr_diamB=0.001;          % 13 Diameter B
WSE_orr_diamC=0.001;       % 15 Diameter C

% Poppet;
rho=850;
D=Pop_orr_diam;
x=Pop_max_x;
Q=[0.00833; 0.01333];  %500, 800l/min
deltaP=[0.4e6; 1e6];   %Mpa
Cdpop=Q./(pi*D*x*sqrt(2*deltaP/rho));
Cdpop=mean(Cdpop);

% Wse Cd's:
WSE_Cd_A=0.33;         % 14 Cd   -   A
WSE_Cd_B=0.4;          % 14 Cd   -   B
WSE_Cd_C=0.1;          % 14 Cd   -   C

%Damper
%Demp_Cd_Leak=0.1;
%load G6CdP;  % File with damper valve ss Cd versus dP
%load G6DempPQ;

% Solenoid Valve force vs time curve:
%load ValveF;

% *****************************************************************
% SYSTEM DEFINITION MATRIX C

% Logic element constants:

% Control Valve constants:
C.Cntr=[WSE_max_x*S    % 1 TOP
   0                     % 2 BOT
   WSE_Mass_eq         % 3 Mass
   kwse*S              % 4 Spring stiff
   cwse                % 5 Damping
   0                     % 6 Flag used for bumpstops (1=TOP, 0=Moving, -1=BOT)
   Aswse*S^2           % 7 As
   Adwse*S^2           % 8 Ad
   Axwse*S^2           % 9 Ax
   WSE_Cd_A            % 10 Cd   -   A
   WSE_orr_diamA*S % 11 Diameter A
   WSE_Cd_B            % 12 Cd   -   B
```

```
   WSE_orr_diamA*S % 13 Diameter B
   WSE_Cd_C            % 14 Cd    -    C
   WSE_orr_diamA*S % 15 Diameter C
   ACompPiston         % 16 Pressure Compensating Chamber Area
   InitDispL];         % 17 Initial Spring Displacement

% Magnetic circuit constants:
C.Mag=[8e-5             % 1 A
   1.2566e-6            % 2 mu0
   200                  % 3 N
   2                      % 4 R
   0.05                 % 5 Lsteel
   1.905e-4];           % 6 Addisional gap (Must NOT equal zero!)

% Damper constants:
%C.Damp=[1              % 1 Damper Rotary Area [1/rad]
%    Demp_Cd_Leak       % 2 Leakage Cd in damper
%    Demp_Vol_A*S^3     % 3 Vol A ------f(damper rotation) !
%    Demp_Vol_B*S^3     % 4 Vol B ------f(damper rotation) !
%    0];                % Set to 1 to include leakage

% Solenoid force curve:
%C.ValveF=ValveF;

% Damper curve:
%C.G6CdP=G6CdP;         % 1 G6CdP - Flow Coefficients for damper = f(DeltaP)
%C.G6DempPQ=G6DempPQ;

% System volumes and constants
C.Assy=[0           % 1 Pp afer orifice
   0                    % 2 Py
   Vx                   % 3 Vol X - Pyp voor wse, gekoppel met relief
   Vdrain           % 4 Vol van drein pyp
   Vb];             % 5 Vol B - Constant volumes in Logic manifold

% Fluid constants
C.Fld=[1.7e9/S          % 1 Bulk Modulus
   1000                 % 2 Reynods transition No for orifices
   850/S^3              % 3 rho - Density
   30e-6                  % 4 nu - Kinematic viscosity
   -10e3];              % 5 Flash off pressure (damp druk) - relative to atmospheric

% ***********************************************************
% Steel H vs B data:
% Histerisis: Colum 1 is incresing psipsi, colum 2 is decreasing
Hdata = 1.0e+004 *[  -1.14392615347300  -1.14392615347300
  -0.72461377630202  -0.72461377630202
  -0.37715360539077  -0.37715360539077
  -0.09870675113842  -0.09870675113842
  -0.01182939354700  -0.01182939354700
  -0.00790000000000  -0.00779100567704
  -0.00450000000000  -0.00444462475461
  -0.00180000000000  -0.00167167038803
  -0.00139460730484  -0.00121326923677
  -0.00122551666032  -0.00088848528571
  -0.00108540091978  -0.00061935541193
  -0.00096929502402  -0.00039634288706
  -0.00087308471262  -0.00021154517007
  -0.00079336073339  -0.00005841387745
  -0.00072729803419   0.00004094369593
  -0.00067255565594   0.00010381309392
  -0.00062719377983   0.00015590936620
  -0.00058960498903   0.00019907856572
  -0.00055845730919   0.00023485041091
  -0.00053264700941   0.00026449249189
  -0.00051125949102   0.00028905518808
  -0.00049353687848   0.00030940888875
  -0.00047885116369   0.00032627483572
  -0.00046668195226   0.00034025068078
  -0.00045659802316   0.00035183166378
  -0.00044824204818   0.00036142816165
  -0.00044131792991   0.00036938023025
  -0.00043558030935   0.00037596965443
  -0.00043082587153   0.00038142993315
  -0.00042688614100   0.00038595455365
  -0.00042362151177   0.00038970384773
  -0.00042091630035   0.00039281067317
```

```
   -0.00041867464645   0.00039538512162
   -0.00041681711616   0.00039751841972
   -0.00041527788710   0.00039928616177
   -0.00041400241607   0.00040075098845
   -0.00041294550621   0.00040196480649
   -0.00041206970550   0.00040297062803
   -0.00041134397957   0.00040380409479
   -0.00041074261202   0.00040449474099
   -0.00041024429315   0.00040506703997
   -0.00040983136482   0.00040554127139
   -0.00040948919474   0.00040593423983
   -0.00040920565798   0.00040625987028
   -0.00040897070729   0.00040652970161
   -0.00040877601710   0.00040675329538
   -0.00040861468848   0.00040693857475
   -0.00040848100469   0.00040709210516
   -0.00040837022858   0.00040721932702
   -0.00040827843476   0.00040732474850
   -0.00040783454167   0.00040783454167
   -0.00040732474850   0.00040827843476
   -0.00040721932702   0.00040837022858
   -0.00040709210516   0.00040848100469
   -0.00040693857475   0.00040861468848
   -0.00040675329538   0.00040877601710
   -0.00040652970161   0.00040897070729
   -0.00040625987028   0.00040920565798
   -0.00040593423983   0.00040948919474
   -0.00040554127139   0.00040983136482
   -0.00040506703997   0.00041024429315
   -0.00040449474099   0.00041074261202
   -0.00040380409479   0.00041134397957
   -0.00040297062803   0.00041206970550
   -0.00040196480649   0.00041294550621
   -0.00040075098845   0.00041400241607
   -0.00039928616177   0.00041527788710
   -0.00039751841972   0.00041681711616
   -0.00039538512162   0.00041867464645
   -0.00039281067317   0.00042091630035
   -0.00038970384773   0.00042362151177
   -0.00038595455365   0.00042688614100
   -0.00038142993315   0.00043082587153
   -0.00037596965443   0.00043558030935
   -0.00036938023025   0.00044131792991
   -0.00036142816165   0.00044824204818
   -0.00035183166378   0.00045659802316
   -0.00034025068078   0.00046668195226
   -0.00032627483572   0.00047885116369
   -0.00030940888875   0.00049353687848
   -0.00028905518808   0.00051125949102
   -0.00026449249189   0.00053264700941
   -0.00023485041091   0.00055845730919
   -0.00019907856572   0.00058960498903
   -0.00015590936620   0.00062719377983
   -0.00010381309392   0.00067255565594
   -0.00004094369593   0.00072729803419
    0.00005841387745   0.00079336073339
    0.00021154517007   0.00087308471262
    0.00039634288706   0.00096929502402
    0.00061935541193   0.00108540091978
    0.00088848528571   0.00122551666032
    0.00121326923677   0.00139460730484
    0.00160000000000   0.00167167038803
    0.00430000000000   0.00444462475461
    0.00770000000000   0.00779100567704
    0.01182939354700   0.01182939354700
    0.09870675113842   0.09870675113842
    0.37715360539077   0.37715360539077
    0.72461377630202   0.72461377630202
    1.14392615347300   1.14392615347300];

Hdata=mean(Hdata');  %This statement elininates the histerisys.
C.Hdata=Hdata';
C.Bvalues =[  -3.00000000000000
  -2.48592831856405
  -2.05994653501290
  -1.70695980870549
  -1.41445990903722
```

-1.17208198111639
-0.97123726284529
-0.80480873858392
-0.66689894475786
-0.55262099079801
-0.45792539015257
-0.37945656505659
-0.31443394024641
-0.26055341212541
-0.21590570190035
-0.17890869949784
-0.14825140083972
-0.12284745187141
-0.10179665315686
-0.08435306093923
-0.06989855431546
-0.05792093186650
-0.04799576158818
-0.03977134096770
-0.03295623425963
-0.02730894533975
-0.02262936019006
-0.01875165577582
-0.01553842403769
-0.01287580278039
-0.01066944091867
-0.00884115510766
-0.00732615928365
-0.00607076894318
-0.00503049881043
-0.00416848648312
-0.00345418619798
-0.00286228642905
-0.00237181296327
-0.00196538567058
-0.00162860263180
-0.00134952980069
-0.00111827811609
-0.00092665307894
-0.00076786437681
-0.00063628526638
-0.00052725318746
-0.00043690454325
-0.00036203779219
-0.00030000000000
0
0.00030000000000
0.00036203779219
0.00043690454325
0.00052725318746
0.00063628526638
0.00076786437681
0.00092665307894
0.00111827811609
0.00134952980069
0.00162860263180
0.00196538567058
0.00237181296327
0.00286228642905
0.00345418619798
0.00416848648312
0.00503049881043
0.00607076894318
0.00732615928365
0.00884115510766
0.01066944091867
0.01287580278039
0.01553842403769
0.01875165577582
0.02262936019006
0.02730894533975
0.03295623425963
0.03977134096770
0.04799576158818
0.05792093186650
0.06989855431546
0.08435306093923

```
    0.10179665315686
    0.12284745187141
    0.14825140083972
    0.17890869949784
    0.21590570190035
    0.26055341212541
    0.31443394024641
    0.37945656505659
    0.45792539015257
    0.55262099079801
    0.66689894475786
    0.80480873858392
    0.97123726284529
    1.17208198111639
    1.41445990903722
    1.70695980870549
    2.05994653501290
    2.48592831856405
    3.00000000000000];
```

A3.3.6

```
function Fsol=WSEDrainSolenoid(t,C)

% WSE model with state for pressure compensating chamber
% This model is a extension of wse3only with the added effect of
% a drain side state and orifice.

% Function used to evaluate several diffirent solenoid options on the
% wse model.
% Neil Janse van Rensburg   8/10/1999

% #1 Magnetic equations option:
if 0   %use method #1
   %DOESN'T WANNA WEK - Sol never opens.
FSolFIX=1;
Vsol=1e-6;          % Solenoid Voltage
if t > 0.01
   Vsol=24*2;
end
if t > 0.05
   Vsol=1e-6;   % DON'T set to zero - ossilasion occurs?!?!?
end
B=psi/C.Mag(1);
gap=C.Cntr(1)-x3+C.Mag(6);
Fa=B*(gap)/C.Mag(2);
% Histerisis is ignored:
Fs=Fa;
i=(Fa+Fs)/C.Mag(3);
Fsol=(0.5*C.Mag(1)*(B^2)/C.Mag(2))*FSolFIX;
psipsi=(Vsol-i*C.Mag(4))/C.Mag(3);
end  % end of method #1

if 0   %use method #2 - Same as #1, but with B,H interpolation...
   % DOESN'T WORK! - Unable to meet inttegr. tolerances
FSolFIX=1;
Vsol=1e-6;          % Solenoid Voltage
if t > 0.01
   Vsol=24*2;
end
if t > 0.05
   Vsol=1e-6;   % DON'T set to zero - ossilasion occurs?!?!?
end
B=psi/C.Mag(1);
gap=C.Cntr(1)-x3+C.Mag(6);
Fa=B*(gap)/C.Mag(2);
% Histerisis is ignored:
Fs=C.Mag(5)*interp1(C.Bvalues(:,1), C.Hdata(:,1), B);
%Fs=Fa;
i=(Fa+Fs)/C.Mag(3);
Fsol=(0.5*C.Mag(1)*(B^2)/C.Mag(2))*FSolFIX;
psipsi=(Vsol-i*C.Mag(4))/C.Mag(3);
end  % end of method #2

% #3 Interpolation option:
%Fsol=0;
%Fsol=16*(1.0*sin(t)+0.5);
```

```
%if t > 0.005
%   Fsol=interp1(C.ValveF(:,1),C.ValveF(:,2),t);
%end

% #4 Constant force and time delays
if 0   % Use method #3
   % This one work's - consider to increase the damping of the system.
%   C.Cntr(5)=C.Cntr(5)*10; % - No difference
   Vsol=24;     % Solenoid Voltage
%   Fsol=0;            % Initialisation
   Delay=0.005;
   if t > 0.1 + Delay
      Vsol=0;% 24*1;
   end
   if t > 0.4 + Delay
      Vsol=24; %0;
   end
   Fsol=Vsol*20;  %- Play with this value - was 20
   psipsi=0;  %Just to keep the changes to code simple
end   % end of method #4

% #5 Exponential solenoid force rise and decay
if 1
   Sig=[0 0
      1 1  %used to be 0.1
      0 3]; %used to be 0.4
   Fsol=Solenoid_Force_Lookup(t,Sig,24,0.03,4);
   % Values tried for tau: 0.2=far to slow - no solution
   %                       0.02 = works but to fast - try more damping
   %                       0.05 = OK, probably the slowest feasible option
   %
   psipsi=0;  %Just to keep the changes to code simple
end % end of #5
```

A3.3.7

```
function [out1,out2,out3] = WseLcDampDEQ(t,y,flag,C);

% COMPLETE FINAL MODEL
% Includes:
% LC 25 Logic Element
% Parallel Damper
% WSE3D valve from the WSEDrainDEQ.m file (Compensating chamber plus drain line state)

% FLOW FROM B TO A - Change 2 line to reverse (line 133 & 173)
% THIS FUNCTION calculates the derivatives of the state vector
global V

% WSE model with state for pressure compensating chamber
% This model is a extension of wse3only with the added effect of
% a drain side state and orifice.

% Now includes the pressure compensating chamber with pressure Pch
% EVENT location at bumpstops
% 3-Way valve ONLY - taken from lc25wse3
% 3-way valve has magnetic circuit
% THE AME counterpart of this model used a flow source at 12LPM
% with a pressure limmiting relief valve.

% Neil Janse van Rensburg
%disp([t])  % Used to debug

% SYSTEM DEFINITION MATRIX IS C VARIABLE
% ==================================================================
% START OF DEQ
if nargin < 3 | isempty(flag)
   % Return dy/dt = f(t,y).

% External Inputs:
Qin=LPMIN(97); %Flow into the system - function of damper speed
%Qin=LPMIN(22);

% SYSTEM VARIABLES:
x=y(1);
xx=y(2);
```

```
x3=y(3);
xx3=y(4);
Pa=y(5);
Pb=y(6);
Pp=y(7);
Pcomp=y(8);

Px=Pa;  %Supply Pressure to WSE from rectifier
% ALTERNATIVE FOR FUTURE USE: PwseIN=max(Pa,Pb)
% since the flow in this model is only in one direction through the LC,
%     the pressure can be set to the highest side.
Py=Pb;  %Pressure in drain line from WSE
% ALTERNATIVE FOR FUTURE USE: PwseOUT=min(Pa,Pb)
%disp(t)    % !!!!!!!!!!!!!!!!!!

% *******************************************************************
% LOGIC VALVE SECTION:
% + = krag op, - = krag af
% LC POPPET MASS DEQ: mxxx + cxx + kx = Fex,
%z=(C.Log(1)-x);    %Used to debug
z=x;
[xxx,FexLOG]=Mass_DEQ(z,xx,C.Log(3),...
   C.Log(5),C.Log(4),C.Log(12),...
   [Pa*C.Log(7) Pb*C.Log(8) -Pp*C.Log(9)]);
FspringLC=Spring_Force(z,C.Log(4),C.Log(12));

% Bumpstop implementation: LOGIC
if C.Log(6) == 1 & sign(xxx) > 0  % het dus bo gestop
   C.Log(6) = 0;      %Reset die flaggie
   xxx = 0;
%   plot(t,0,'mx')  %Used to debug
end
if C.Log(6) == -1 & sign(xxx) < 0 % het dus onder gestop
   C.Log(6) = 0;      %Reset die flaggie
   xxx = 0;
%   plot(t,0.008,'mx')  %Used to debug
end
% Jippo trick to fix acceleration
if x > C.Log(2) & x < C.Log(1)    % ie x is between the bumpstops
   xxx=(FexLOG)/C.Log(3);
end
if x > C.Log(1)
   x=C.Log(1);
end
if x < C.Log(2)
   x=C.Log(2);
end

% *******************************************************************
% SOLENOID FORCE SECTION:
Fsol=WseLCDampSOLENOID(t,C);  %Solenoid force calculation function
% POPPET MASS DEQ: mxxx + cxx + kx = Fex
[xxx3,FexCNTRL]=Mass_DEQ((C.Cntr(1)-x3),xx3,C.Cntr(3),...
   C.Cntr(5),-C.Cntr(4),C.Cntr(17),...
   [Px*C.Cntr(7) -Pcomp*C.Cntr(16) -Fsol]);

% Bumpstop implementation:
if 0  %FUTURE USE
%[x3 xx3 xxx3 C.Cntr(6)]=BumpStop(x3, xx3, xxx3, C.Cntr(6),...
%                                 FexCNTRL, C.Cntr(1), C.Cntr(2));
else
if C.Cntr(6) == 1 & sign(xxx3) > 0  % het dus bo gestop
   C.Cntr(6)=0;     %Reset die flaggie
   %      disp('Control Valve Plak Bo')
   xxx3=0;
end
if C.Cntr(6) == -1 & sign(xxx3) < 0  % het dus onder gestop
   C.Cntr(6)=0;     %Reset die flaggie
   %      disp('Control Valve Plak onder')
   xxx3=0;
end
% Jippo trick om die versnelling te fix:
if x3 > C.Cntr(2) & x3 < C.Cntr(1)   % ie x is between the bumpstops
   xxx3=(FexCNTRL)/C.Cntr(3);
end
if x3 > C.Cntr(1)
   x3=C.Cntr(1);
```

```
end
if x3 < C.Cntr(2)
   x3=C.Cntr(2);
end
end
% ***************************************************************
% CALCULATE FLOWRATES:  using: [Q]=orifice(deltaP,x,Cd,D,Retr,nu,rho)
% Logic flow:
dP_DAMPER=(Pa-Pb);
Qa = orifice(dP_DAMPER,x,C.Log(10),C.Log(11),400,C.Fld(4),C.Fld(3));
% ---------------------
% Damper flow:
if 0   % For the original experimental curve
   TopPLim=4.4955e6;
   BotPLim=-2.3789e6;
end
if 1   % For the appended experimental curve
   TopPLim=6e6;
   BotPLim=-4e6;
end
if 0   % For the first faulty curve used
   TopPLim=34e6;
   BotPLim=-28.7e6;
end
if dP_DAMPER > TopPLim %Prevent extrapolation in the damper Cd curve
   dP_DAMPER = TopPLim;
elseif dP_DAMPER < BotPLim
   dP_DAMPER = BotPLim;
end
%     Q1=   int:      ( dP )               ( Q )             dP1
Qdamp=interp1(C.DampCurve(:,1),C.DampCurve(:,2),dP_DAMPER);

% ---------------------
% Control valve flowrates:
% A Orifice, Supply -> X   flow
%[Q] = orifice(deltaP,x,Cd,D,Retr,nu,rho) - SOME HELP IF YOU WANTED!
QwseA = orifice((Px-Pp),x3,C.Cntr(10),C.Cntr(11),300,C.Fld(4),C.Fld(3));
% B Orifice, X -> Drain   flow
TOP3=C.Cntr(1);
BOT3=C.Cntr(2);
xb=(TOP3-BOT3)-x3;  %Poppet height from top
QwseB = orifice((Pp-Py),xb,C.Cntr(12),C.Cntr(13),C.Fld(2),C.Fld(4),C.Fld(3));
% C Orifice, Supply -> Drain   flow
xc=(TOP3-BOT3)*(x3-TOP3)*(x3-BOT3)/(-0.25*(TOP3^2+BOT3^2)+0.5*TOP3*BOT3); %Parabolic poppet
height
QwseC = orifice((Px-Py),xc,C.Cntr(14),C.Cntr(15),C.Fld(2),C.Fld(4),C.Fld(3));

% Orifice in Pressure compensating chamber
D=0.0008;
QCcomp = orifice((Px-Pcomp),D/4,0.1,D,300,C.Fld(4),C.Fld(3));
% ---------------------
% System
Dout=0.025;
Patm=0; %Atmospheric pressure
Qout=orifice((Pb-Patm),Dout/4,0.3,Dout,100,C.Fld(4),C.Fld(3));

% ***************************************************************
% NODE FLOW SUMMATION:  (QC_ = compression flow)
QCa=Qin-Qa-Qdamp;
QCb=Qa+Qdamp-Qout;
QCp=QwseA-QwseB;
%Qx=QwseA+QwseC;  %Inlet flow to Control valve
%     Qch is to small to incorporate (assumption)
%Qy=QwseB+QwseC;  %Drain flow from Control valve

% ---------------------------------------------------------------
% COMPRESSIBILITY & Pressure derivative calculation
% P'=(B/V)*sigma(Q)
PaPa=C.Fld(1)*QCa/C.Assy(1);
PbPb=C.Fld(1)*QCb/C.Assy(2);
PpPp=C.Fld(1)*QCp/C.Assy(3);
PcompPcomp=C.Fld(1)*QCcomp/C.Assy(5);

% ***************************************************************
% Assemble State vector to return to ODE integrator
out1=[xx
```

```
    xxx
    xx3
    xxx3
    PaPa
    PbPb
    PpPp
    PcompPcomp];
% END OF DEQ

% ******************************************************************
% Provide graphical output
L=(size(V.Out,1)+1);
%Pch=0; %fascilitate easy removal of Pch variable
V.Out(L,:)=[x x3 Pa Pb Pp FexLOG Fsol ...
      Pa*C.Log(7) Pb*C.Log(8) -Pp*C.Log(9)...
      Qin Qa Qdamp QCa ...
       FspringLC];   %Used to return values to calling function
V.t(L,:)=[t];

% ==================================================================
else  %Alternative flag use of DEQ - (Event location)
  switch(flag)
  case 'events'         % Used only if odeset('Events','on').
     % Return event vectors VALUE, ISTERMINAL, and DIRECTION.
     % Locate zero-crossings
     TOP=C.Log(1);
     BOT=C.Log(2);
     TOP3=C.Cntr(1);
     BOT3=C.Cntr(2);
     x=y(1);
     x3=y(3);
     %*******************
 %    Sig=[0 0
 %     1 0.1
 %     0 0.4];
  [Fsol Sig]=WseLcDampSOLENOID(t,C);
% Fsol=Solenoid_Force_Lookup(t,Sig,24,0.02,20);
    %******************
    %plot(t,(x3-TOP3)*1e5,'m*')    % Used to debug
     %plot(t,TOP3,'m-')    % Used to debug - shows TOP3 on graph
      %       [           3-WAY          ]
      out1 = [(x-BOT); (x-TOP); (x3-BOT3); (x3-TOP3); Sig]'; % VALUE: ie ui aan watter een
cross
      out2 = [1; 1; 1; 1; 1]';    % IS_TERMINAL?: stop at zeros of height
      out3 = [-1; 1; -1; 1; 0]'; % DIRECTION
  end
end
```

```
function [ttout,yout,teout,yeout,ieout,V] = WseLcDampSOLVE;
```

A3.3.8

```
% COMPLETE FINAL MODEL
% Includes:
% LC 25 Logic Element
% Parallel Damper
% WSE3D valve from the WSEDrainDEQ.m file (Compensating chamber plus drain line state)

% THIS FUNCTION sets initial conditions, call the DEQ solver and provides output
clear
global V
format compact
format long %bank
% 3-Way valve ONLY
% 3-way valve has magnetic circuit

% SYSTEM VARIABLES:
%x=y(1);
%xx=y(2);
%x3=y(3);
%xx3=y(4);
%Pa=y(5);
%Pb=y(6);
%Pp=y(7);
%Pcomp=y(8);
%%%Px=y(9);   %unused

% Neil Janse van Rensburg
```

```
[C] = WseLcDampDIMENSIONS;  % Function to calculate system variables
% V is a return variable for solved values;
V.Out=[];
V.t=[];
tic; Fl=flops;

tstart = 0;
tfinal = 5.0;
% states is:
%       x,      xx, x3,     xx3, Pa, Pb, Pp, Pcomp
y0 = [0.007; 0; 0.0005; 0; 10e6; 10e6; 10e6; 10e6];  % Initial conditions
options = odeset('reltol',1e-3,'abstol',1e-5,'Events','on','refine',1,...
   'stats','off','BDF','on','MaxStep',1);
tout = tstart; yout = y0.';
teout = []; yeout = []; ieout = [];

while tstart < tfinal
    % Solve until the first terminal event.
    [t,y,te,ye,ie] = ode15s('WseLcDampDEQ',[tstart tfinal],y0,options,C);
    % Accumulate output.
   nt = length(t);
   tout = [tout; t(2:nt)];
   yout = [yout; y(2:nt,:)];
   teout = [teout; te];   % Events at tstart are never reported.
   yeout = [yeout; ye];
   ieout = [ieout; ie];
   % Reset the "initial" conditions after integrator halt
   y0(1) = y(nt,1);
   y0(2) = y(nt,2);
   y0(3) = y(nt,3);
   y0(4) = y(nt,4);   %Put this mess into a loop sometime!!
   y0(5) = y(nt,5);
   y0(6) = y(nt,6);
   y0(7) = y(nt,7);
   y0(8) = y(nt,8);
%  y0(9) = y(nt,9);
   tstart = t(nt);
   % Set the new initial conditions according to type of zerocross.
   if length(ie) > 1
      warning(['More that one simultanious event at t='num2str(te')])
      disp([te ie])
   end

   if ~isempty(ie)
  i=length(te);
% ZEROCROSSING DETECTION for x variable:
   if ie(i) == 1
      C.Log(6)=-1;
      y0(1) = C.Log(2);% 'x BOT' value
      y0(2) = 0;   %eps; %???
      disp(['* Logic HIT THE BOTTOM *  t=' num2str(te')])
   end
   if ie(i) == 2
      C.Log(6)=1;
      y0(1) = C.Log(1);  % 'x TOP' value
      y0(2) = 0;
      disp(['* Logic HIT THE TOP *  t=' num2str(te')])
   end

   % ZEROCROSSING DETECTION for x3 variable:
   if ie(i) == 3
      C.Cntr(6)=-1;
      y0(3) = C.Cntr(2);% 'x3 BOT' value
      y0(4) = 0;   %eps; %???
      disp(['* CONTROL HIT THE BOTTOM *  t=' num2str(te')])
   end
   if ie(i) == 4
      C.Cntr(6)=1;
      y0(3) = C.Cntr(1);  % 'x3 TOP' value
      y0(4) = 0;
      disp(['* CONTROL HIT THE TOP *  t=' num2str(te')])
   end
   if ie(i) == 5
      disp(['*********  ZEROCROSS OF SOLENOID *  t=' num2str(te')])
   end

end  %End of zerocrossing detection loop
```

```
end %End of integration loop*********************************************

if nargout > 0
  ttout = tout;
end
CPUt=toc;
Fll=flops-Fl;

format bank   %Provide integration performance output
disp('          e-time   Flops              Flops/sek')
disp([CPUt Fll Fll/CPUt])
format

if 1  %Provide Graphical Output
   disp('Working on Graphical Output')
%V.Out(L,:)=[1x 2x3     3Pa 4Pb 5Pp    6FexLOG 7Fsol ...
%      8Pa*C.Log(7) 9Pb*C.Log(8) 10-Pp*C.Log(9)...
%      11Qin 12Qa 13Qdamp 14QCa
%           15FspringLC];   %Used to return values to calling function

figure(1), clf, hold on
plot(V.t,V.Out(:,1),'r.',V.t,V.Out(:,2),'g.')
plot(ttout,yout(:,1),'r',ttout,yout(:,3),'g')
title('Poppet displacement  Lc=r.  Wse=g.')
xlabel('Time    [s]')
ylabel('Displacement    [m]')
yaxis([-0.002 0.01])

figure(2), clf, hold on
plot(V.t,V.Out(:,3)/1e6,'m.',V.t,V.Out(:,4)/1e6,'bo',V.t,V.Out(:,5)/1e6,'r+')
plot(ttout,yout(:,5)/1e6,'m',ttout,yout(:,6)/1e6,'b',ttout,yout(:,7)/1e6,'r')
title('Pa=m.   Pb=bo   Pp=r+')
ylabel('Pressure    [MPa]')
%yaxis([-80e6 80e6])

%figure(3), clf, hold on
%plot(V.t,V.Out(:,6),'r+',V.t,V.Out(:,8),'go',...
%   V.t,V.Out(:,9),'bo',V.t,V.Out(:,10),'r.',...
%   V.t,V.Out(:,15),'bx')
%title('Fex=r+    PaA=go     PbA=bo    PpA=r.   Fspring=bx')
%ylabel('Force    N')

%figure(4), clf, hold on
%plot(V.t,V.Out(:,7),'bx')
%title('Fsol')

%figure(4), clf, hold on
%plot(V.t,V.Out(:,15),'bx')
%title('Fspring on LC')

figure(5), clf, hold on
plot(V.t,m3ps(V.Out(:,11)),'r+',V.t,m3ps(V.Out(:,12)),'go',...
   V.t,m3ps(V.Out(:,13)),'bo',V.t,m3ps(V.Out(:,14)),'r.')
title('Qin=r+   Qa=go    Qdamp=bo   QCa=r.')
ylabel('Flowrate   LPM')

disp('Graphical output is complete')
end
disp('Simulation is complete')
```

A3.3.9

```
function [C] = WseLcDampDIMENSIONS;

% COMPLETE FINAL MODEL
% Includes:
% LC 25 Logic Element
% Parallel Damper
% WSE3D valve from the WSEDrainDEQ.m file (Compensating chamber plus drain line state)

% THIS FUNCTION is used to calculate and store the true dimensions of valve
% and valve blocks.
disp('The dimension function WseLcDamp was called')
disp('**********************************************')
%TT=input('Continue?')
% SCALE the dimensions:
% Length=10*length
```

```
S=1;

% MASS:
Poppet_mass=0.0793;  % LC25 poppet - kg
Poppet_spring_mass=0.00909; % CrackPress=?, LC25, kg
%Volgens RAO, Mech.vibration:
Poppet_Mass_eq=Poppet_mass+(1/3)*Poppet_spring_mass;

WSE_mass=0.020;  % WSE poppet  %AS used in AME
WSE_spring_mass=0.0009; %wse spring mass
%Volgens RAO, Mech.vibration:
WSE_Mass_eq=WSE_mass+(1/3)*WSE_spring_mass;

% VOLUMES:
% Klepblok;
%Vdrain=(pi/4)*(0.025^2)*0.265; %2; %0.05; % Volume to rear of wse
Va=(pi/4)*(0.020^2)*1;
Vb=(pi/4)*(0.020^2)*1;
Vp=(pi/4)*(0.025^2)*0.04; %Volume in front of WSE

%Damper:
Demp_Vol_A=0.001;  % F(x) !!!
Demp_Vol_B=0.001;  % F(x) !!!

% SPRING STIFFNESS:
% Shigley formula: p363
kwse=27089; %AS used in AME [N/m]
InitDispWSE=0.001;  % Initial Spring Displacement

kLC=4500; %[N/m] =4.5N/mm soos bepaal uit shigley
InitDispLC=0.004;

% AREAS:
%Poppet;
Aa=189e-6;   %m^2  According to the catalog
Ab=426e-6;   %m^2
Ax=616e-6;   %m^2

%WSE Valve:
wseballdia=0.004;
wseseatdia=0.003;
Aswse=(pi/4)*(wseseatdia)^2;        % 7 As
Adwse=(pi/4)*(0.6*wseballdia)^2;       % 8 Ad
Axwse=(pi/4)*(0.7*wseballdia)^2;       % 9 Ax
ACompPiston=(pi/4)*(0.0028^2); %Compensating chamber piston dia.

%DAMPING:
cwse=2000; %0;
cLC25=200;

% MOVEMENTS:
Pop_max_x=0.008;   %m
WSE_max_x=0.0009;   %m

% CD:
% DIAMETERS:
% Poppet orifice:
Pop_orr_diam=0.021;  %m
WSE_orr_diamA=0.002;          % 11 Diameter A
WSE_orr_diamB=0.001;          % 13 Diameter B
WSE_orr_diamC=0.001;       % 15 Diameter C

% Poppet;
%rho=850;
%D=Pop_orr_diam;
%x=Pop_max_x;
%Q=[0.00833; 0.01333];  %500, 800l/min
%deltaP=[0.4e6; 1e6];   %Mpa
%Cdpop=Q./(pi*D*x*sqrt(2*deltaP/rho));
%Cdpop=mean(Cdpop);
Cdpop=0.9;

% Wse Cd's:
WSE_Cd_A=0.33;        % 14 Cd   -   A
WSE_Cd_B=0.4;         % 14 Cd   -   B
WSE_Cd_C=0.1;         % 14 Cd   -   C
```

```
%Damper Caracteristics
load G6DempPQ;  % File with damper valve ss Cd versus dP
load damperexpcurve.dat; %Saved Format = [Bar LPM]

% Solenoid Valve force vs time curve:
%load ValveF; % - Atlternative sugested by Elyse Bottle

% ***************************************************************
% SYSTEM DEFINITION MATRIX C

% Logic element constants:
%C.SolenoidSig=[0 0];  % Continuesly open
C.SolenoidSig=[0 0
      1 1  %used to be 0.1
      0 3]; %used to be 0.4

C.Log=[Pop_max_x        % 1 TOP Bumpstop  [m]
    0*S                 % 2 BOT Bumpstop  [m]
    Poppet_Mass_eq      % 3 Mass          [kg]
    kLC*S                  % 4 Spring stiff  [N/m]
    cLC25*1             % 5 Damping
    0                      % 6 Flag used for bumpstops (1=TOP, 0=Moving, -1=BOT)
    Aa*S^2              % 7 Aa           [m^2]
    Ab*S^2              % 8 Ab           [m^2]
    Ax*S^2              % 9 Ax           [m^2]
    Cdpop                  % 10 Cd of annular orifice in Logic
    Pop_orr_diam*S      % 11 Diameter of annular orifice in Logic  [m]
    InitDispLC];        % 12 Initial Spring displacement

% Control Valve constants:
C.Cntr=[WSE_max_x*S     % 1 TOP
    0                      % 2 BOT
    WSE_Mass_eq         % 3 Mass
    kwse*S              % 4 Spring stiff
    cwse                % 5 Damping
    0                      % 6 Flag used for bumpstops (1=TOP, 0=Moving, -1=BOT)
    Aswse*S^2           % 7 As
    Adwse*S^2           % 8 Ad
    Axwse*S^2           % 9 Ax
    WSE_Cd_A            % 10 Cd    -    A
    WSE_orr_diamA*S % 11 Diameter A
    WSE_Cd_B            % 12 Cd    -    B
    WSE_orr_diamA*S % 13 Diameter B
    WSE_Cd_C            % 14 Cd    -    C
    WSE_orr_diamA*S % 15 Diameter C
    ACompPiston         % 16 Pressure Compensating Chamber Area
    InitDispWSE];          % 17 Initial Spring Displacement

% Magnetic circuit constants:
C.Mag=[8e-5             % 1 A
    1.2566e-6           % 2 mu0
    200                 % 3 N
    2                      % 4 R
    0.05                % 5 Lsteel
    1.905e-4];          % 6 Addisional gap (Must NOT equal zero!)

% Damper constants:
C.Damp=[1               % 1 Damper Rotary Area [1/rad]
    0                      % 2 Unused
    Demp_Vol_A*S^3      % 3 Vol A ------f(damper rotation) !
    Demp_Vol_B*S^3      % 4 Vol B ------f(damper rotation) !
    0];                 % Set to 1 to include leakage

% Solenoid force curve:
%C.ValveF=ValveF;

% Damper curve:
% Curve must be: [dP Q]
%C.DampCurve=G6DempPQ;
damperexpcurve=[-40 -200  %This step is because MATLAB cannot extrapolate & flow is close to
the limit
   damperexpcurve(:,1) damperexpcurve(:,2)
   60 200];
%damperexpcurve(:,2)=-1*damperexpcurve(:,2); % Fix the damper directionality - NO, ERROR
C.DampCurve=[damperexpcurve(:,1)*1e5 lpmin(damperexpcurve(:,2))];

% System volumes and constants
```

```
C.Assy=[Va      % 1 Vol A
    Vb              % 2 Vol B
    Vp              % 3 Vol P
    0               % 4 Vol X
    2.356e-9;   % 5 Vol Comp  dia <1mm, L=30mm  %VERY stiff!
    0               % unused
    0               % unused
    0               % unused
    0];         % unused

% Fluid constants
C.Fld=[1.7e9/S          % 1 Bulk Modulus
    1000                % 2 Reynods transition No for orifices
    850/S^3             % 3 rho - Density
    30e-6                   % 4 nu - Kinematic viscosity
    -10e3];             % 5 Flash off pressure (damp druk) - relative to atmospheric

% ****************************************************************
```

SUPPORT FUNCTIONS:

A3.3.10

```
function [Q,AreaInner,AreaOuter]=orificeSB(deltaP,x,Cd,D,Retr,nu,rho,ball);

% [Q AreaInner AreaOuter] = orificeSB(deltaP,x,Cd,D,Retr,nu,rho,ball)
%
% The function calculates flow through a SHARP SEATED BALL POPPET orifice
% by implementing the proposed method of A. Ellman and area calculations of
AMESim.
% This model uses laminar and turbulent transitions since pure laminar models
% have a singularity in the Jacobian at zero pressure difference.
% This can cause numerical oscillation and instability.
%
% Inputs to the model:
% deltaP        -> Pressure difference over the orifice    [Pa]
% Cd            -> Coefficient of discharge
% D         -> Diameter of the orifice seat (default = 10mm)    [m]
% Retr      -> Reynolds no for transition to turbulent (Typical = 1000)
% nu            -> Fluid kinematic viscosity
% rho           -> Fluid density
% x         -> Opening height     [m]
% ball      -> Ball poppet diameter (default = 15mm)  [m]
% Output: Flow and
% Effective area for the pressure to work in on the poppet.
%                       (Units required indicated in [])
% The flow area is the perpendicular distance between the seat and poppet. Where this
% line intersecs the poppet, the effective area is calculated. The flow area is limited to
% the seat diameter area.
%
% Neil Janse van Rensburg    18/01/1999
% Revision 1 - AMESim Area calculation: 30/11/1999 NJR

if nargin == 7
   ball=0.015;  %default ball diameter = 15mm
end
if nargin == 6
   rho=800;
end
if nargin == 5
   nu=0.800;
end
if nargin == 4
   Retr=1000;
end
if nargin == 3
   D=0.010;
end

if ball <= D
   error('Ball diameter smaller or equal to seat diameter')
```

```
end

Temp=2*x/D+sqrt((ball/D)^2-1);
Area=(0.25*pi*D^2)*((Temp^2+1-(ball/D)^2)/sqrt(Temp^2+1));
AreaMax=0.25*pi*D^2;
if Area > AreaMax %Limit the maximum area to the throught area
   Area=AreaMax;
end

Deff=ball/sqrt(1+Temp^2);  % effective Diameter for pressure to act on
AreaInner=0.25*pi*(Deff)^2;        % effective inner Area
AreaOuter=0.25*pi*ball^2-AreaInner; % effective outer Area
DH=4*Area/(pi*(D+Deff));    % Hydraulic Diameter

tempD=DH+eps;  %Prevent division by zero, without affecting the performance

%DeltaP for transition to occur:
dtf=(225*Retr^2*rho*nu^2)/(128*Cd^2*tempD^2); %D should be DH

% Laminar / Turbulent conditions:
if abs(deltaP) < abs(dtf)     % Laminar condition
   Q=sign(deltaP)*Area*nu*Retr*(45*((abs(deltaP)/dtf)^3)...
      -150*((deltaP/dtf)^2)+225*(abs(deltaP)/dtf))/(64*tempD);  %D should be DH
else      % Turbulent condition
   Q=sign(deltaP)*Cd*Area*sqrt(abs(2*deltaP/rho));
end
```

A3.3.11

```
function [Q,AreaInner,AreaOuter] =
orificeSC(deltaP,x,Cd,D,Retr,nu,rho,alpha,PopDiam);

% [Q AreaInner AreaOuter] = orificeSC(deltaP,x,Cd,D,Retr,nu,rho,alpha,PopDiam)
%
% The function calculates flow through a SHARP SEATED, CONICAL POPPET orifice
% by implementing the proposed method of A. Ellman and area calculations of AMESim.
% This model uses laminar and turbulent transitions since pure laminar models
% have a singularity in the Jacobian at zero pressure difference.
% This can cause numerical oscillation and instability.
%
% Inputs to the model:
% deltaP       -> Pressure difference over the orifice   [Pa]
% Cd           -> Coefficient of discharge
% D        -> Diameter of the orifice  [m]
% Retr     -> Reynolds no for transition to turbulent (Typical = 1000)
% nu           -> Fluid kinematic viscosity
% rho          -> Fluid density
% x        -> Opening height   [m]
% alpha    -> Conical poppet angle (default = 45deg) - Measured from vertical to
%              the seat angle   [Degrees]
% PopDiam  -> Total Poppet diameter, used to determine the effective area [m]
%
% Output: Flow and
% Effective areas for the pressure to work in on the poppet.
%                    (Units required indicated in [])
% The flow area is the perpendicular distance between the seat and poppet. Where this
% line intersecs the poppet, the effective area is calculated. The flow area is limited to
% the seat diameter area.
%
% Neil Janse van Rensburg    18/01/1999
% Revision 1 - AMESim Area calculation: 30/11/1999 NJR

if nargin == 8
   PopDiam=0.025;
end
if nargin == 7
   alpha=45;
end
if nargin == 6
   rho=800;
end
if nargin == 5
   nu=0.800;
end
if nargin == 4
   Retr=1000;
end
```

```
if nargin == 3
   D=0.010;
end

alpha=alpha*(2*pi/360);  %Convert degrees to radians, as used by MATLAB

% Where the intersection lines leave the conical poppet point
xCRIT=(D/2)/(sin(alpha)*cos(alpha));
if x > xCRIT
   x=xCRIT;
end

Area=pi*x*sin(alpha)*(D-(x*sin(alpha)*cos(alpha)));
AreaMax=0.25*pi*D^2;
if Area > AreaMax
   Area=AreaMax;
end

Deff=D-2*x*sin(alpha)*cos(alpha);% effective Diameter
AreaInner=0.25*pi*(Deff)^2;       % effective inner Area
AreaOuter=0.25*pi*PopDiam^2-AreaInner; % effective outer Area
DH=2*x*sin(alpha);                % Hydraulic Diameter

tempD=DH+eps;  %Prevent division by zero, without affecting the performance

%DeltaP for transition to occur:
dtf=(225*Retr^2*rho*nu^2)/(128*Cd^2*tempD^2);

% Laminar / Turbulent conditions:
if abs(deltaP) < abs(dtf)      % Laminar condition
   Q=sign(deltaP)*Area*nu*Retr*(45*((abs(deltaP)/dtf)^3)...
      -150*((deltaP/dtf)^2)+225*(abs(deltaP)/dtf))/(64*tempD);
else      % Turbulent condition
   Q=sign(deltaP)*Cd*Area*sqrt(abs(2*deltaP/rho));
end
```

A3.3.12

```
function [Q] = orifice(deltaP,x,Cd,D,Retr,nu,rho);

% [Q] = orifice(deltaP,x,Cd,D,Retr,nu,rho)
%
% The function calculates flow through a orifice by implementing
% the proposed method of A. Ellman. This model uses laminar and
% turbulent transitions since pure laminar models have a
% singularity in the Jacobian at zero pressure difference.
% This can cause numerical oscillation and instability.
%
% Inputs to the model:
% deltaP       -> Pressure difference over the orifice
% Cd           -> Coefficient of discharge
% D        -> Diameter of the orifice
% Retr         -> Reynolds no for transition to turbulent (Typical = 1000)
% nu           -> Fluid kinematic viscosity
% rho          -> Fluid density
% x        -> Opening height
%              - for a circular orifice use x = D/4
%              - For a poppet type orifice use x = poppet height
% Output: Flow
%
% Neil Janse van Rensburg    18/01/1999

if nargin == 6
   rho=800
end
if nargin == 5
   nu=0.800
end
if nargin == 4
   Retr=1000
end
if nargin == 3
   D=0.010
end

%DeltaP for transition to occur:
dtf=(225*Retr^2*rho*nu^2)/(128*Cd^2*D^2);
```

```
% Laminar / Turbulent conditions:
if abs(deltaP) < abs(dtf)
   % Laminar condition
   Q=sign(deltaP)*pi*x*nu*Retr*(45*((abs(deltaP)/dtf)^3)...
     -150*((deltaP/dtf)^2)+225*(abs(deltaP)/dtf))/64;
   % NOTE: Original formula has pi*x = Area/Diameter
else
   % Turbulent condition
   Q=sign(deltaP)*Cd*pi*D*x*sqrt(abs(2*deltaP/rho));
   % NOTE: Original formula has pi*D*x = Area
end
```

A3.3.13

```
function [xxx, Ftot] = Mass_DEQ(x,xx,m,c,k,InitDisp,Fexternal)
% This function solves the equation mx"+cx'+kx=Fexternal for x"
%        [xxx, Ftot] = Mass_DEQ(x,xx,m,c,k,InitDisp,Fexternal)
% Fexternal may be a vector of values
%
% Inputs:
%        x is the displacement, xx is the speed (x')
% Outputs:
%        xxx is the acceleration output (x"), Ftot is the total force acting on the mass
% Addisional outputs is the effective total force acting on the mass.
% The spring force and damping are considered to work in direction A,
% with positive Fexternal's opposing it. To change the spring/damping forces direction
% use a negative k or c.
%
% EQUATIONS:
%        Fspring=Spring_Force(x,k,InitDisp);
%        Fdamp=xx*c;
%        Ftot=sum(Fexternal)-Fdamp-Fspring;
%            xxx=Ftot/m;
%
%
% Neil Janse van Rensburg 8/10/1999

% Compressed Version for fast computation
Ftot=sum(Fexternal)-xx*c-Spring_Force(x,k,InitDisp);
xxx=Ftot/m;
```

A3.3.14

```
function Q=IdealReliefValve(Pin, Pout, Pcrack, Gradient)
% Ideal Relief valve flow calculator with linear pressure drop
%      Q=IdealReliefValve(Pin, Pout, Pcrack, Gradient)
% The flow Q is a function of the input and output pressures (Pin,Pout),
%  the Cracking (or opening pressure, Pcrack) and the pressuredrop gradient
% The Gradient is in m^3/s/Pa  (=LPM/Bar /0.6)

% causes no solution if the grad is to high!?
%Gradient=20/0.6;  %((LPM/Bar)/0.6 = m3/pa)
dPrelief=Pin-Pout-Pcrack;
if dPrelief >= 0
   Q = dPrelief*Gradient;  % AME Implementation
else
   Q = 0;
end
```

A3.3.15

```
function [F, Signal]=Solenoid_Force_Lookup(t,Sig,V,tau,Ampl)
% Gives a simple exponential rise and decay force trend
% for use in solenoid models.
%       F=Solenoid_Force_Lookup(t,D)
% F is the force on a given time t, Signal output aids in discontinuity
location
% The voltage profile is defined in the matrix Sig, example:
%        Sig=[0 0   %Off at t=0 - Must define initial state
%             1 1   %On at t=2
%             0 3]; %Off at t=3
%
% V is the Voltage input, tau the rise and fall time constant and
% Ampl is the force multiplication factor (Force = Ampl*V)
%
```

```
% This function does NOT take vector time inputs
%
% Neil Janse van Rensburg

F=V*Sig(1,1);
Signal=Sig(1,1);
if length(Sig(:,1)) > 1
for i=2:length(Sig(:,1))
   if t > Sig(i,2) & Sig(i,1) == 1    %i.e. Switch on
      F=F+V-V*exp(-(t-Sig(i,2))/tau);
      Signal=Sig(i,1);
   end
   if t > Sig(i,2) & Sig(i,1) == 0    %i.e. Switch off
      F=F-(V-V*exp(-(t-Sig(i,2))/tau));
      Signal=Sig(i,1);
   end
end
end
F=F*Ampl;
```

A3.3.16

```
function OUT=UDDC(t,D)
% User Defined Duty Cycle Creator
%     OUT=UDDC(t,D)
% This function takes a profile definition matrix D and gives the
% profile for any valid time t in the profile.
% The profile matrix D has the form:
%              Begin Value - End value - Duration
% Sample
%D=[10 10 2
%   0 0 5
%   10 10 3
%   10 -10 2];
% This means that the output must be held at 10 for 2 seconds,
% then at 0 for 5 seconds. Thereafter at 10 for 3 seconds
% and then sweep from +10 to -10 in 2 seconds
%
% Neil Janse van Rensburg       7/10/1999

line=1;
for k=1:length(D(:,1))
   S=sum(D(1:k,3));
   if t > S
      line=k+1;
   end
end
if line > length(D(:,1))
   error('time requested outside the valid sequence')
end

if line == 1
   START=0;
else
   START=sum(D(1:line-1,3));
end

X=[START START+D(line,3)];
Y=[D(line,1) D(line,2)];
OUT=interp1(X,Y,t);


% optional graphical output
if 0
   % ***************
D=[10 10 2
   0 0 5
   10 10 3
   10 -10 2];
figure(1)
clf
hold on
for t=0:0.1:12
   plot(t,uddc(t,D),'.')
end
   % ***************
```

```
end
```

A3.3.17

```
function Fspring=Spring_Force(x,k,InitDisp)
% Calculates the spring Force Fspring for a given displacement x,
% spring stiffness k, and initial spring displacement InitDisp.
%        Fspring=Spring_force(x,k,InitDisp)
%   Fspring=k*(x+InitDisp)
%
% A posistive x causes compression and therefore a increase in force
% A posistive InitDisp causes a higher initial compression force
%
% Neil Janse van Rensburg   8/10/1999

Fspring=k*(x+InitDisp);
```

A3.3.18

```
function [m3ps]=LPMIN(lpmin)

% [M3PS]=LPMIN(lpmin)
% This function takes a value in liters per minute (lpmin)
% and converts it to m^3/s
%
% See also M3PS for the inverse
% Neil Janse van Rensburg

m3ps = lpmin/60000;
```

A3.3.19

```
function [lpmin]=M3PS(m3ps)

% [lpmin]=M3PS(m3ps)
% This function takes a value in m^3/s
% and converts it to liters per minute (lpmin)
%
% See also LPMIN for the inverse
% Neil Janse van Rensburg

lpmin = m3ps*60000;
```

A3.3.20

```
function xline(xpos,tipe)
% xline(xpos,tipe)
% xline plot a vertical line across the screen at the specified xpos value
% tipe is the usual linetipe parameters (color)
% xline returns the figure hold status to what it was
% See also yline
% Neil Janse van Rensburg

if nargin < 2
   tipe='b';
end

V=axis;
H=ishold;
hold on
X=ones(1,20)*xpos;
Y=linspace(V(3),V(4),20);
plot(X,Y,tipe);

if H==0
   hold off
else
   hold on
```

```
end
```

A3.3.21

```
function yline(ypos,tipe)
% yline(ypos,tipe)
% yline plot a horisontal line across the screen at the specified y value
% tipe is the usual linetipe parameters (color)
% yline returns the figure hold status to what it was
% See also xline
% Neil Janse van Rensburg

if nargin < 2
   tipe='b';
end

V=axis;
H=ishold;
hold on
X=linspace(V(1),V(2),20);
Y=ones(1,20)*ypos;
plot(X,Y,tipe);

if H==0
   hold off
else
   hold on
end
```

A3.3.22

```
function rottext(angle)
% Text Rotaion Tool
% ROTTEXT(angle)
% Angle is a optional (Default 90Deg) input to specify the incremental angle of
rotation
% This tool allows you to rotate text incremental by 90 Degrees, or by a
specified value
% Rotation is CounterClockwise
%
% Neil Janse van Rensburg
disp('Click on the text to be rotated');
ginput(1);

if nargin ==0
   angle=90;
end

CurrentRotation=get(gco,'Rotation');
set(gco,'Rotation',CurrentRotation+angle);
disp(['The new text angle is: ' num2str(CurrentRotation+angle)])
```

SENSITIVITY ANALYSIS:

A3.3.23

```
% Automated AMESim Run producer
% Neil Janse van Rensburg 3 Feb 2000

% AMESim Runner!!!!!!!!!!!!!!!!!!!!!!!!!!!
% The main functions are: AmeGo.m and Singlerunner.m
% *********************

tic
filen='Sens2CP';     %The AMESim Filename
AA=335; % Pa
BB=341; % Pb
PP=338; %Pp
CC=55;  % Lc Disp
DD=44;  %WSE disp

% Selected flow settings:
%FL_SET=5:25:405;
%FL_SET=10:5:50;
FL_SET=[30 50 80 140 210];    %The flows tested for


% -------------------------------------------------------------
%NORMAL RUN!!!!!!!!!!
RR='_run1_';
for k=FL_SET %In this part AME runs & Matlab saves the info
   ameputp(filen,'CONS0 instance 1 constant value [null]',k);
   SingleRunner(k, filen, RR); %Defined later on
end
% -------------------------------------------------------------
%RUN 2+3 !!!!!!!!!!
AmeGO('CONS0 instance 3 constant value [null]',[0.036 0.044 0.04],...
   filen, '_run2_', '_run3_',FL_SET)
% -------------------------------------------------------------
%RUN 4+5 !!!!!!!!!!
AmeGO('CONS0 instance 2 constant value [null]',[0.0027 0.0033 0.003],...
   filen, '_run4_', '_run5_',FL_SET)
% -------------------------------------------------------------
%RUN 6+7 !!!!!!!!!!
AmeGO('BAP12 instance 1 piston diameter [mm]',[2.52 3.08 2.8],...
   filen, '_run6_', '_run7_',FL_SET)
% -------------------------------------------------------------
%RUN 8+9 !!!!!!!!!!
AmeGO('SPR0 instance 1 spring rate [N/m]',[24380 29798 27089],...
   filen, '_run8_', '_run9_',FL_SET)
% -------------------------------------------------------------
%RUN 10+11 !!!!!!!!!!
AmeGO('SPR0 instance 1 initial spring displacement [m]',[-0.0009 -0.0011 -0.001],...
   filen, '_run10_', '_run11_',FL_SET)
% -------------------------------------------------------------
%RUN 12+13 !!!!!!!!!!
AmeGO('BAI21 instance 1 mass [kg]',[0.0741 0.0905 0.08233],...
   filen, '_run12_', '_run13_',FL_SET)
% -------------------------------------------------------------
%RUN 14+15 !!!!!!!!!!
AmeGO('BAI21 instance 1 viscous friction [N/(m/s)',[900 1100 1000],...
   filen, '_run14_', '_run15_',FL_SET)
% -------------------------------------------------------------
%RUN 16+17 !!!!!!!!!!
AmeGO('BAP15 instance 1 spring stiffness [N/mm]',[3.15 3.85 3.5],...
   filen, '_run16_', '_run17_',FL_SET)
% -------------------------------------------------------------
%RUN 18+19 !!!!!!!!!!
AmeGO('BAP15 instance 1 spring force at zero displacement [N]',[54 66 60],...
   filen, '_run18_', '_run19_',FL_SET)
% -------------------------------------------------------------
%RUN 20+21 !!!!!!!!!!
AmeGO('BAP15 instance 1 piston diameter [mm]',[22.5 27.5 25],...
   filen, '_run20_', '_run21_',FL_SET)
% -------------------------------------------------------------
%RUN 22+23 !!!!!!!!!!
AmeGO('CV002 instance 1 check valve cracking pressure [bar]',[1.35 1.65 0],...
   filen, '_run22_', '_run23_',FL_SET)
% -------------------------------------------------------------
%RUN 24+25 !!!!!!!!!!
```

```
AmeGO('CV002 instance 2 check valve cracking pressure [bar]',[1.35 1.65 1.5],...
   filen, '_run24_', '_run25_',FL_SET)
% -------------------------------------------------------------
%RUN 26+27 !!!!!!!!!!
AmeGO('OR001 instance 1 pressure gain [null]',[0.9 1.1 1],...
   filen, '_run26_', '_run27_',FL_SET)
% -------------------------------------------------------------
%RUN 28+29 !!!!!!!!!!
AmeGO('HR22B instance 1 diameter [mm]',[18 22 20],...
   filen, '_run28_', '_run29_',FL_SET)
% -------------------------------------------------------------
%RUN 30+31 !!!!!!!!!!
AmeGO('OR000 instance 3 equivalent orifice diameter [mm]',[18 22 20],...
   filen, '_run30_', '_run31_',FL_SET)
% -------------------------------------------------------------
%RUN 32+33 !!!!!!!!!! - Special mod, because many pipe's
RR='_run32_';
RubberStiff=9000;  %Bar
ameputp(filen,'HL03 instance 1 Young*',RubberStiff);
ameputp(filen,'HL02 instance 3 Young*',RubberStiff);
ameputp(filen,'HL01 instance 1 Young*',RubberStiff);
ameputp(filen,'HL05 instance 1 Young*',RubberStiff);
ameputp(filen,'HL02 instance 4 Young*',RubberStiff);
ameputp(filen,'HL01 instance 3 Young*',RubberStiff);
ameputp(filen,'HL05 instance 2 Young*',RubberStiff);
for k=FL_SET %In this part AME runs & Matlab saves the info
   ameputp(filen,'CONS0 instance 1 constant value [null]',k);
   SingleRunner(k, filen, RR); %Defined later on
end
RR='_run33_';
RubberStiff=11000;  %Bar
ameputp(filen,'HL03 instance 1 Young*',RubberStiff);
ameputp(filen,'HL02 instance 3 Young*',RubberStiff);
ameputp(filen,'HL01 instance 1 Young*',RubberStiff);
ameputp(filen,'HL05 instance 1 Young*',RubberStiff);
ameputp(filen,'HL02 instance 4 Young*',RubberStiff);
ameputp(filen,'HL01 instance 3 Young*',RubberStiff);
ameputp(filen,'HL05 instance 2 Young*',RubberStiff);
for k=FL_SET %In this part AME runs & Matlab saves the info
   ameputp(filen,'CONS0 instance 1 constant value [null]',k);
   SingleRunner(k, filen, RR); %Defined later on
end
RubberStiff=10000;  %Reset the parameter
ameputp(filen,'HL03 instance 1 Young*',RubberStiff);
ameputp(filen,'HL02 instance 3 Young*',RubberStiff);
ameputp(filen,'HL01 instance 1 Young*',RubberStiff);
ameputp(filen,'HL05 instance 1 Young*',RubberStiff);
ameputp(filen,'HL02 instance 4 Young*',RubberStiff);
ameputp(filen,'HL01 instance 3 Young*',RubberStiff);
ameputp(filen,'HL05 instance 2 Young*',RubberStiff);
% -------------------------------------------------------------


if 0
% MANUAL ADJUSTMENT OF OIL PARAMTERS:
%RUN 34+35 !!!!!!!!!!
RR='_run34_';  %Set the Bulk Mod to 18000Bar and save AME model
for k=FL_SET %In this part AME runs & Matlab saves the info
   ameputp(filen,'CONS0 instance 1 constant value [null]',k);
   SingleRunner(k, filen, RR); %Defined later on
end
RR='_run35_';  %Set the Bulk Mod to 22000Bar and save AME model
for k=FL_SET %In this part AME runs & Matlab saves the info
   ameputp(filen,'CONS0 instance 1 constant value [null]',k);
   SingleRunner(k, filen, RR); %Defined later on
end
% -------------------------------------------------------------
%RUN 36+37 !!!!!!!!!!
RR='_run36_';  %Set the Kin Visc to 41.4 cSt and save AME model
for k=FL_SET %In this part AME runs & Matlab saves the info
   ameputp(filen,'CONS0 instance 1 constant value [null]',k);
   SingleRunner(k, filen, RR); %Defined later on
end
RR='_run37_';  %Set the Kin Visc to 50.6 cSt and save AME model
for k=FL_SET %In this part AME runs & Matlab saves the info
   ameputp(filen,'CONS0 instance 1 constant value [null]',k);
   SingleRunner(k, filen, RR); %Defined later on
```

```
end
end

% TEMPLATE:
% -------------------------------------------------------------
%RUN ?+? !!!!!!!!!!
%AmeGO('',[- + =]...
%   filen, '_run?_', '_run?_',FL_SET)

ttaken=toc;
disp('Ek is klaar! ------------------------------------------')
disp(['This simulation took: ' num2str(ttaken/60) ' minutes'])
```

A3.3.24

```
function AMEcapture(fname,discribe,fnameout)
% Capture AMESim model parameters and results!
% CAPTURE('fname',discribe,'fnameout')
%    'fname' is the name of the AMEsim model to be captured
%    Let discribe = 1 to print a list of SOLVED variables with line numers
%    Let discribe = 2 to print a list of PARAMETERS with line numers
%    discription is a optional variable to describe te test and data in
%    'fnameout' is a optional name for the output file (default = fname)
% The output file will be fname.mat in Matlab binary format
%
% Neil Janse van Rensburg
% 1 July 1999


[R,S]=ameloadt(fname);
[par,val]=amegetp(fname);

% ***********************************************************
% Display calculated variable names
if discribe==1
   disp('Model RESULT variables')
   for i=1:length(S(:,1))
      disp([int2str(i) ' - ' S(i,:)])
   end

% ***********************************************************
% Display Model parameter names
elseif discribe==2
   disp('Model PARAMETERS names')
   j=1;
   C=[num2str(j) ' - '];
   for i=1:length(par)
      C=[C par(i)];
      if par(i)==char(10)
         disp(C(1:length(C)-1))
         j=j+1;
         C=[];
         C=[C num2str(j) ' - '];
      end
   end
else

% ***********************************************************
% Save the system into a single file with results
if nargin < 3, fnameout = fname; end
if nargin < 2, discribe = ['Results file from AMESim model: ',fname]; end

save(fnameout,'par','val','R','S','discribe')
end
```

A3.3.25

```
function AmeGO(variab,range,filen,name1,name2,FL_SET)
% Complete amesim sensitivity run producer
% Neil Janse van Rensburg

% ----------------------
ameputp(filen,variab,range(1));
for k=FL_SET %In this part AME runs & Matlab saves the info
   ameputp(filen,'CONS0 instance 1 constant value [null]',k);
```

```
   disp('************************************************')
   disp(['Current run: ' name1])
   disp(['Flow Rate: ' num2str(k) '  Setting: ' num2str(range(1))])
   disp('****************************************************')
   [R,S]=amerun(filen,0,2,[0 2 0 0 4]);
   B=[filen name1 num2str(k)];
   disp(B)
   % Reduce variable amount:  (otherwise the file is 16 MEG!)
   t=R(1,:);
   Pa=R(335,:)/10;  %/10 vir Bar to MPa
   Pb=R(341,:)/10;
   Pp=R(338,:)/10;
   DispLC=R(55,:);
   DispWSE=R(44,:);
   save(B,'t','Pa','Pb','Pp','DispLC','DispWSE');
   disp('\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\')
   disp('')
end

% ++++++++++++++++++++
ameputp(filen,variab,range(2));
for k=FL_SET %In this part AME runs & Matlab saves the info
   ameputp(filen,'CONS0 instance 1 constant value [null]',k);
   disp('**********************************************************')
   disp(['Current run: ' name2])
   disp(['Flow Rate: ' num2str(k) '  Setting: ' num2str(range(2))])
   disp('*********************************************************')
   [R,S]=amerun(filen,0,2,[0 2 0 0 4]);
   B=[filen name2 num2str(k)];
   disp(B)
   % Reduce variable amount:  (otherwise the file is 16 MEG!)
   t=R(1,:);
   Pa=R(335,:)/10;  %/10 vir Bar to MPa
   Pb=R(341,:)/10;
   Pp=R(338,:)/10;
   DispLC=R(55,:);
   DispWSE=R(44,:);
   save(B,'t','Pa','Pb','Pp','DispLC','DispWSE');
   disp('\/\/\//\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\')
   disp('')
end

% RE-Set parameter changes:
ameputp(filen,variab,range(3));
```

A3.3.26

```
function Singlerunner(k,filen,RR)
% Single AMESim run producer - used for sensitivity studies
% Neil Janse van Rensburg

% ---------------------
disp('*******************************')
disp(k)
disp('*******************************')
[R,S]=amerun(filen,0,2,[0 2 0 0 4]);
B=[filen RR num2str(k)];
disp(B)
% Reduce variable amount:  (otherwise the file is 16 MEG!)
t=R(1,:);
Pa=R(335,:)/10;  %/10 vir Bar to MPa
Pb=R(341,:)/10;
Pp=R(338,:)/10;
DispLC=R(55,:);
DispWSE=R(44,:);
save(B,'t','Pa','Pb','Pp','DispLC','DispWSE');
disp('\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\/\')
disp('')
```

A3.3.27

```
function SysDamp_delay_analise(RunCase)
% Neil Janse van Rensburg

% Delay analiser, Automated for the simulation runs!!
```

```
%For reference:
%plot(Result(:,3)*1000,Result(:,1),'r.',Result(:,5)*1000,Result(:,1),'g.')

tic
%RunCase=1;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%RR=['run' num2str(RunCase)];
RR=['base'];
filename=['F:\neil\system\syssens\Sens2CP_' RR];
%FL_SET=[30 50 80 140 210];
FL_SET=[5 10 15 20 22 25 30 35 40 45 50 60 70 80 90 97 100 110 120 130 140 150 170 190 210
230];
FL_SET=[15 20 22 25 30 35 40 45 50 60 70 80 90 97 100 110 120 130 140 150 170 190 210 230];

SF=1000;
index=0;

if 1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
   % THIS SECTION USES Displacement TO CALCULATE TIMEDELAY
   for k=FL_SET
%    k=90;  %watter een van die cases hierbo
%    if k < 99
%       RunNo=['0' num2str(k)];
%    else
%       RunNo=[num2str(k)];
%    end
    RunNo=num2str(k);
   disp(['Nommer:     DeltaP: ' RunNo])
   load([filename '_' RunNo]);
   data=[Pa Pb];  % CAREFULL!!!!
   XX=DispLC;
   %   data=data';
    discard=1;
    xline(t(discard))
   Pers=5;
    t=t';
    TNEW=[t (1:length(t))'];
   dPseries=(Pa-Pb);
   dPinit=mean(dPseries(1:30));  %Quick way to get pressure for these runs
   %                  - if stabilising run was used!!!!
   disp('*****************************************************************')
   disp(['Flow setting: ' num2str(k) '  Initial Pressure: ' num2str(dPinit)])
   figure(1)
   plot(t,XX)
   title('Displacement with 98% & 2% lines')
   xlabel('Time     [s]')
   ylabel('[mm]')
   %disp('Pick the LOW value starting point')
   %[XXs YY]=ginput(1);    %remember - x is itv t!
   %disp('Pick the LOW value ending point')
   %[XXe YY]=ginput(1);
   %index1=round(XXs*SF);
   %index2=round(XXe*SF);
   index1=0.1*SF;
   index2=0.4*SF;

   %disp('Pick the HIGH value starting point')
   %[XXs YY]=ginput(1);    %remember - x is itv t!
   %disp('Pick the HIGH value ending point')
   %[XXe YY]=ginput(1);
   %index3=round(XXs*SF);
   %index4=round(XXe*SF);
   index3=0.85*SF;
   index4=1*SF;


   dXLow=mean(XX(index1:index2));
   dXinit=mean(XX(index3:index4));
   [L02 L98]=cutoff(dXinit, dXLow, Pers);
   yline(L98,'g')
   yline(dXinit,'r')
   yline(L02,'g')
   yline(dXLow,'r')
    swtime1=0.5;
   xline(swtime1,'m');
```

```
    swtime2=1;
    xline(swtime2,'m');
    zoom on
    grid on

% Determine the delay times automatically:
%   disp('Pick the DISCARD point')
%   [XXe YY]=ginput(1);
%   discard=round(interp1(TNEW(:,1),TNEW(:,2),XXs));
%   discard=index1;

%   disp('Pick the CUT point')
%   [XXe YY]=ginput(1);
%   CUT=round(XXe*1000);
CUT=0.9*SF;
xline(t(CUT))

  % CUT = Mid point of data
   % The first half of the data
   for i=discard:CUT
      if XX(i)>L02
%          L98
%          disp('Yupidoda 1')
         block=[t(i-1) XX(i-1)
            t(i) XX(i)];
         base1=interp1(block(:,2),block(:,1),L02);
         break
      end
   end
   for i=discard:CUT
      if XX(i)>L98
%         disp('Yupidoda 2')
         block=[t(i-1) XX(i-1)
            t(i) XX(i)];
         delay981=interp1(block(:,2),block(:,1),L98);
         break
      end
   end
   % The other end of the signal
   for i=CUT:length(XX)
      if XX(i)<L98
%         disp('Yupidoda 3')
         block=[t(i-1) XX(i-1)
            t(i) XX(i)];
         base2=interp1(block(:,2),block(:,1),L98);
         break
      end
   end
   for i=CUT:length(XX)
      if XX(i)<L02
%         disp('Yupidoda 4')
         block=[t(i-1) XX(i-1)
            t(i) XX(i)];
         delay982=interp1(block(:,2),block(:,1),L02);
         break
      end
   end

   index=index+1;
   DISPResult(index,:)=[dPinit (base1-swtime1) (delay981-swtime1)  ...
         (base2-swtime2) (delay982-swtime2)];
%   disp(Result(index,:))
   xline(DISPResult(index,2)*1+swtime1,'r')
   xline(DISPResult(index,3)*1+swtime1,'r')
   xline(DISPResult(index,4)*1+swtime2,'r')
   xline(DISPResult(index,5)*1+swtime2,'r')

   disp(' ')
   W=input('continue?');
   disp(' **************************')
   disp(' ')
end


%^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
% THIS SECTION USES Pressure TO CALCULATE TIMEDELAY
index=0;
```

```
for k=FL_SET

     RunNo=num2str(k);
    disp(['Nommer:      DeltaP: ' RunNo])
    load([filename '_' RunNo]);
    data=[Pa Pb];  % CAREFULL!!!!
    XX=DispLC;
    %   data=data';
     discard=1;
     xline(t(discard))
    Pers=5;

    t=t';
     TNEW=[t (1:length(t))'];
    dPseries=(Pa-Pb);
    dPinit=mean(dPseries(1:30));  %Quick way to get pressure for these runs
    %                  - if stabilising run was used!!!!
    disp('**************************************************************')
    disp(['Flow setting: ' num2str(k) '  Initial Pressure: ' num2str(dPinit)])

    figure(1)
    plot(t,dPseries)
    title('Pressure Drop acros LC')
    xlabel('Time     [s]')
    ylabel('[MPa]')

    index1=0.1*SF;
    index2=0.4*SF;
    index3=0.85*SF;
    index4=1*SF;

    dPinit=mean(dPseries(index1:index2));
    dPLow=mean(dPseries(index3:index4));
    [L02 L98]=cutoff(dPinit, dPLow, Pers);
    yline(L98,'r')
    yline(dPinit,'g')
    yline(L02,'g')
    yline(dPLow,'g')
     swtime1=0.5;
    xline(swtime1,'m');
    swtime2=1;
    xline(swtime2,'m');
    zoom on
    grid on

     CUT=0.9*SF;
     xline(t(CUT))


    % The first half of the data
    for i=discard:CUT
       if dPseries(i)<L98
          block=[t(i-1) dPseries(i-1)
             t(i) dPseries(i)];
          base1=interp1(block(:,2),block(:,1),L98);
          break
       end
    end
    for i=discard:CUT
       if dPseries(i)<L02
          block=[t(i-1) dPseries(i-1)
             t(i) dPseries(i)];
          delay981=interp1(block(:,2),block(:,1),L02);
          break
       end
    end
    % The other end of the signal
    for i=CUT:length(dPseries)
       if dPseries(i)>L02
          block=[t(i-1) dPseries(i-1)
             t(i) dPseries(i)];
          base2=interp1(block(:,2),block(:,1),L02);
          break
       end
    end
    % SPecial Check for this data range:
    if dPseries(length(dPseries))<L98
```

```
      disp('YTF----------------------------')
      delay982=1;
   else
      for i=CUT:length(dPseries)
         if dPseries(i)>L98
            block=[t(i-1) dPseries(i-1)
               t(i) dPseries(i)];
            delay982=interpl(block(:,2),block(:,1),L98);
            break
         end
      end
   end

   index=index+1;
   PAResult(index,:)=[dPinit (base1-swtime1) (delay981-swtime1)  ...
         (base2-swtime2) (delay982-swtime2)];
%   disp(PAResult(index,:))
   xline(PAResult(index,2)*1+swtime1,'r')
   xline(PAResult(index,3)*1+swtime1,'r')
   xline(PAResult(index,4)*1+swtime2,'r')
   xline(PAResult(index,5)*1+swtime2,'r')

   disp(' ')
   W=input('Continue');
   disp(' ***************************')
   disp(' ')
end
end  %end of: if 0

DISPResult
PAResult

if 0
   % Risky to overrite saved data!!! - Rather Cut and paste
   sname=['DISPResult_Run' num2str(RunCase)];
   save(sname, 'DISPResult');
   sname=['PAResult_Run' num2str(RunCase)];
   save(sname, 'PAResult');
end

if 0  % SPecial section to determine the SS values..... (with LC open)
   index=0;
for k=FL_SET
   disp(['Nommer:      DeltaP: ' num2str(k)])
   load([filename '_' num2str(k)]);
    t=t';
   dPseries=(Pa-Pb);
   dPinit=mean(dPseries(1:30));  %Quick way to get pressure for these runs
   %                  - if stabilising run was used!!!!
   disp('****************************************************************')
   disp(['Flow setting: ' num2str(k) '  Initial Pressure: ' num2str(dPinit)])
   figure(1)
   plot(t,DispLC,t,Pa)
   title('Displacement with 98% & 2% lines')
   xlabel('Time     [s]')
   ylabel('[mm]')

   index1=0.9*SF;
   index2=1.0*SF;

   DispSS=mean(DispLC(index1:index2));
   PaSS=mean(Pa(index1:index2));
   yline(DispSS,'g')
   yline(PaSS,'r')
    swtime1=0.5;
   xline(swtime1,'m');
   swtime2=1;
   xline(swtime2,'m');
   zoom on
   grid on

   index=index+1;
   SSResult(index,:)=[dPinit DispSS PaSS]
   disp(' ')
   W=input('Continue?');
   disp(' ***************************')
   disp(' ')
```

```
end
end %enf of: if=0
if 0
   % Risky to overrite saved data!!! - Rather Cut and paste
   %Format of the data: initP, SSDisplacement[Bar], SS Pressure[MPa]
   sname=['SSResult_Run' num2str(RunCase)];
   save(sname, 'SSResult');
end

if 0 %Temporary chech of initial pressures
   for i=1:33
%       load(['F:\neil\system\syssens\PAResult_Run' num2str(i)]);
      load(['F:\neil\system\syssens\DISPResult_Run' num2str(i)]);
      disp([num2str(i) ' - ' num2str(DISPResult(:,1)')])
   end
end

% Change % Change % Change % Change % Change % Change % Change % Change
if 0 %this algorithm determines the %change in Results: 30, 80, 210LPM
   load(['F:\neil\system\syssens\DISPResult_Run' num2str(1)]);  %Displ
   %  Reduce to the used variables:
   DISPResult(4,:)=[];
   DISPResult(2,:)=[];
    DISPResult(:,4)=[];
    DISPResult(:,2)=[];
   DISPResult(:,1)=[];
   DispREF=[DISPResult(1,:) DISPResult(2,:) DISPResult(3,:)];
   load(['F:\neil\system\syssens\PAResult_Run' num2str(1)]);  %Pressure
   PAResult(4,:)=[];
   PAResult(2,:)=[];
    PAResult(:,4)=[];
    PAResult(:,2)=[];
   PAResult(:,1)=[];
   PaREF=[PAResult(1,:) PAResult(2,:) PAResult(3,:)];
   load(['F:\neil\system\syssens\SSResult_Run' num2str(1)]);   %SS
   SSResult(4,:)=[];  %50
   SSResult(2,:)=[];  %140
   SSResult(:,1)=[];  %idP
         %displ SS(30 80 210)       Press SS(30 80 210):
   SSRef=[SSResult(:,1)' SSResult(:,2)'];
   index=0;
   for i=2:37
      load(['F:\neil\system\syssens\DISPResult_Run' num2str(i)]);
      load(['F:\neil\system\syssens\PAResult_Run' num2str(i)]);
      load(['F:\neil\system\syssens\SSResult_Run' num2str(i)]);   %SS
      DISPResult(4,:)=[];
       DISPResult(2,:)=[];
        DISPResult(:,4)=[];
        DISPResult(:,2)=[];
      DISPResult(:,1)=[];
      %Reformat open30 close30 open80 close80 open210 close210
      DISPResult=[DISPResult(1,:) DISPResult(2,:) DISPResult(3,:)];

      PAResult(4,:)=[];
       PAResult(2,:)=[];
        PAResult(:,4)=[];
        PAResult(:,2)=[];
      PAResult(:,1)=[];
      %Reformat open30 close30 open80 close80 open210 close210
      PAResult=[PAResult(1,:) PAResult(2,:) PAResult(3,:)];

      SSResult(4,:)=[];  %50
       SSResult(2,:)=[];  %140
      SSResult(:,1)=[];  %idP
      %Reformat: Disp:30 80 210 Press:30 80 210
      SSResult=[SSResult(:,1)' SSResult(:,2)'];

      % Persentage Change between parameters:
      per1=((DISPResult-DispREF)./DispREF)*100
      per2=((PAResult-PaREF)./PaREF)*100
      per3=((SSResult-SSRef)./SSRef)*100
      index=index+1;
      changeDISP(index,:)=per1;
      changePA(index,:)=per2;
      changeSS(index,:)=per3;
   end
```

```
end
if 0
    save Master_TableDISP.txt changeDISP -ascii
    save Master_TablePA.txt changePA -ascii
   save Master_TableSS.txt changeSS -ascii
end

if 1
   format compact
   format short
   for i=1:36
      if 0
      disp('***************************************')
      disp(['Run: ' num2str(i+1) ' ------- DISPLACEMENT'])
      disp([' 30 MPa - Opening: ' num2str(changeDISP(i,1)) ' Closing: '
num2str(changeDISP(i,2)) ...
            ' SS: ' num2str(changeSS(i,1))])
      disp([' 80 MPa - Opening: ' num2str(changeDISP(i,3)) ' Closing: '
num2str(changeDISP(i,4)) ...
            ' SS: ' num2str(changeSS(i,2))])
      disp(['210 MPa - Opening: ' num2str(changeDISP(i,5)) ' Closing: '
num2str(changeDISP(i,6)) ...
            ' SS: ' num2str(changeSS(i,3))])

      disp(' ')
      disp(['Run: ' num2str(i+1) ' ------- PRESSURE'])
      disp([' 30 MPa - Opening: ' num2str(changePA(i,1)) ' Closing: ' num2str(changePA(i,2))
...
            ' SS: ' num2str(changeSS(i,4))])
      disp([' 80 MPa - Opening: ' num2str(changePA(i,3)) ' Closing: ' num2str(changePA(i,4))
...
            ' SS: ' num2str(changeSS(i,5))])
      disp(['210 MPa - Opening: ' num2str(changePA(i,5)) ' Closing: ' num2str(changePA(i,6))
...
            ' SS: ' num2str(changeSS(i,6))])
      disp(' ')
     end
      if 1  %Number only alternative:
      disp([num2str(changeDISP(i,1)) ' ' num2str(changeDISP(i,2)) ' ' num2str(changeSS(i,1))])
      disp([num2str(changeDISP(i,3)) ' ' num2str(changeDISP(i,4)) ' ' num2str(changeSS(i,2))])
      disp([num2str(changeDISP(i,5)) ' ' num2str(changeDISP(i,6)) ' ' num2str(changeSS(i,3))])
      disp([num2str(changePA(i,1)) ' ' num2str(changePA(i,2)) ' ' num2str(changeSS(i,4))])
      disp([num2str(changePA(i,3)) ' ' num2str(changePA(i,4)) ' ' num2str(changeSS(i,5))])
      disp([num2str(changePA(i,5)) ' ' num2str(changePA(i,6)) ' ' num2str(changeSS(i,6))])
      disp('************************')
      end

   end
end

toc
```

A3.3.28

```
function [ValueLow, ValueHigh] = Cutoff(LowData, HighData, Pers)
% Calculates a perentage of the data for cutoff purposes
%       [ValueLow ValueHigh] = Cutoff(HighData, LowData, Pers)
% Pers is the persentage below the HighData and above the LowData value
% that must be calcutaled
% ValueLow and ValueHigh is the calculated Pers cutoff values
%
% Neil Janse van Rensburg     2 November 1999


ValueLow=HighData-(HighData-LowData)*(Pers/100);
ValueHigh=LowData+(HighData-LowData)*(Pers/100);
```

Sensitivity Analysis

A 3.4

A sensitivity analysis was performed on the AMESim valve system model by altering model parameters with plus or minus 10%. Data extracted from the results include the opening and closing time delay trends and steady state valve open error across a range of operating pressures. These data fields were extracted from both the pressure and displacement time trends. This represents a massive amount of information and the table in paragraph 3.10 gives the maximum, minimum and average change taken from all the variables and all the operating pressures for any specific parameter change sensitivity run.

As mentioned in paragraph 3.10, any change less than 1.5% should be considered with care. The accuracy of the simulation output file was set to 1 ms intervals. A 1 ms change in the result provides a change of more than 1.5% in the calculated sensitivity.

The table below shows the standard model parameter values with their respective plus or minus 10% changed values, as used in the simulations. For reference, the calculated sensitivities and a graphical representation is given below the table of all the sensitivity runs conducted.

Run	Parameter	Element AME Name	std value	-10% Value	+10% Value
1	Standard run	-	-	-	-
2+3	WSE: Tau on	CONSO-3	0.04	0.036	0.044
4+5	WSE: Tau off	CONSO-2	0.003	0.0027	0.033
6+7	WSE: Chamber diameter	BAP12-1	2.8mm	2.52	3.08
8+9	Spring K- wse	SPRO-1	27089N/m	24380	29798
10+11	Spring Init Disp -wse	SPRO-1	-1mm	-0.9	-1.1
12+13	LC: Poppet Mass	BAI21-1	82.33g	74.1	90.5
14+15	LC: Viscous Friction	BAI21-1	1000Ns/m	900	1100
16+17	LC: Spring K	BAP15-1	3.5N/mm	3.15	3.85
18+19	LC: Spring Force @ Zero	BAP15-1	60N	54	66
20+21	LC: Rear chamber diam	BAP15-1	25mm	22.5	27.5
22+23	CP#1: Cracking P ->x	CV002-1	0Bar	?	?
24+25	CP#2: Cracking P y->	CV002-2	1.5Bar	1.35	1.65

26+27	Damper: dP Gain	OR001-1	1	0.9	1.1
28+29	Drain elbow: Diam	HR22B-1	18mm	16.2	19.8
30+31	TestB: 'quickC' Diam	OR000-3	20mm	18	22
32+33	TestB: Rubber pipe stiffness	HL03-1 HL02-3 HL01-1 HL05-1 HL02-4 HL01-3 HL05-2	10000 Bar	9000	11000
34+35	OIL: Bulk Modulus	-	20000Bar	18000	22000
36+37	OIL: Kinematic viscosity	-	50cSt	45	55

<u>Using the tables and figures below</u>

The tables and figure below might require some explanation. They consist of three main columns and tree main rows. The three columns represent three different valve operating conditions (initial pressure drops across the closed valve system, ie 30, 80 and 210 MPa) For each of these operating conditions, two simulation runs were computed, one with the specified parameter increased by 10% and one with the specified parameter decreased by 10%. For all these runs, six sets of data was extracted. These are presented in the table rows. The final time delay for the opening and closing behaviour based on pressure (Pa) and poppet displacement (LC25) are shown in the first four rows. The steady state pressure and displacement error (difference between experimental and simulation runs) are given in the last two rows. The rightmost column show the maximum change observed in that row (independent of sign). The maximum, minimum and average of the last column is given in paragraph 3.10 as an overview of the sensitivity analysis.

The figures contain the final delay times for the opening and closing behaviours of the valve system (the top figure is based on pressure, and the bottom on poppet displacement). Furthermore the figures show more valve operating conditions than the tables.

Exponential Solenoid Time Constant: OPENING							
Run:	30 MPa		80MPa		210MPa		|max|
2+3	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.1	Opening						
Displacement	0.00	2.49	0.00	2.31	0.00	2.13	**2.489**
Pressure A	0.00	1.81	0.00	1.76	0.00	1.53	**1.808**
	Closing						
Displacement	0.00	-0.07	0.00	0.00	0.00	-0.00	**0.074**
Pressure A	0.00	0.04	0.00	0.03	0.00	-0.00	**0.043**
	Steady State						
Displacement	0.00	-0.05	0.00	-0.01	0.00	-0.01	**0.050**
Pressure A	0.00	0.55	0.00	0.06	0.00	0.02	**0.550**

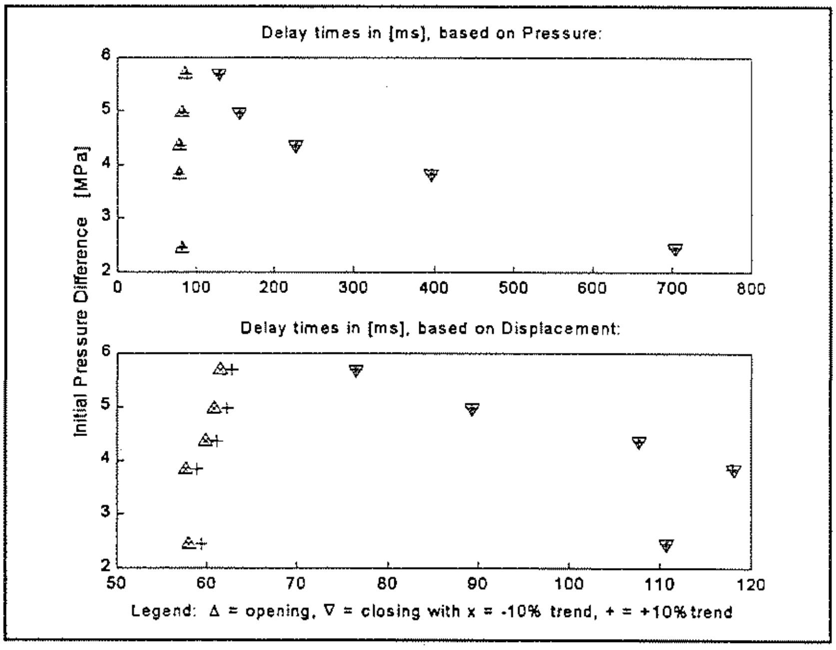

Figure A3.4.1 Solenoid time constant: Opening

Exponential Solenoid Time Constant: CLOSING							
Run: 4+5 Fig A3.4.2	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
	Opening						
Displacement	1.25	1.25	1.19	1.19	1.06	1.06	**1.254**
Pressure A	0.89	0.89	0.90	0.90	0.77	0.77	**0.896**
	Closing						
Displacement	-0.70	0.59	-0.64	0.65	-0.92	0.92	**0.924**
Pressure A	-0.04	0.09	-0.27	0.31	-0.55	0.54	**0.554**
	Steady State						
Displacement	-0.04	-0.04	0.01	0.01	-0.01	-0.01	**0.037**
Pressure A	0.33	0.33	0.02	0.02	0.01	0.01	**0.334**

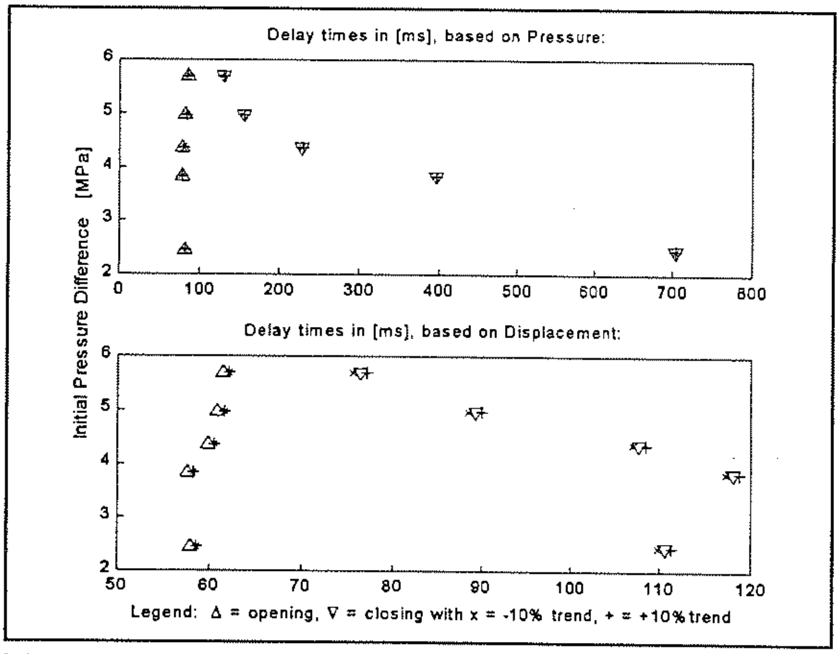

Figure A3.4.2 Solenoid time constant: Closing

Pilot Valve Pressure Compensating Chamber Diameter							
Run:	30 MPa		80MPa		210MPa		|max|
6+7	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.3	Opening						
Displacement	2.34	0.09	3.09	-0.87	3.58	-1.57	**3.577**
Pressure A	1.71	0.07	2.36	-0.67	2.58	-1.13	**2.575**
	Closing						
Displacement	-0.15	0.13	-0.18	0.28	-0.44	0.67	**0.672**
Pressure A	0.07	-0.03	-0.04	0.12	-0.27	0.38	**0.380**
	Steady State						
Displacement	-0.02	-0.02	0.01	-0.01	-0.01	-0.00	**0.018**
Pressure A	0.40	0.12	0.04	-0.01	0.02	0.00	**0.397**

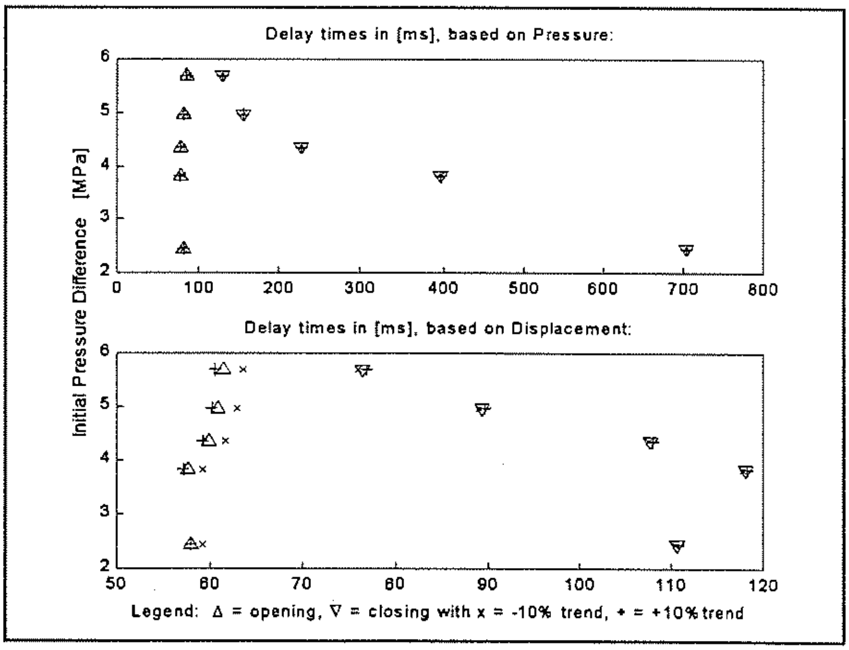

Figure A3.4.3 WSE Compensating chamber diameter

Pilot Valve Spring Stiffness							
Run:	30 MPa		80MPa		210MPa		|max|
8+9	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.4	Opening						
Displacement	0.42	2.13	0.38	1.98	0.34	1.85	**2.134**
Pressure A	0.33	1.53	0.29	1.51	0.24	1.33	**1.533**
	Closing						
Displacement	0.56	-0.53	0.59	-0.50	0.86	-0.74	**0.858**
Pressure A	0.05	-0.03	0.27	-0.19	0.50	-0.45	**0.499**
	Steady State						
Displacement	-0.02	-0.01	0.00	0.01	-0.00	-0.01	**0.019**
Pressure A	0.16	0.51	0.01	0.03	0.00	0.02	**0.505**

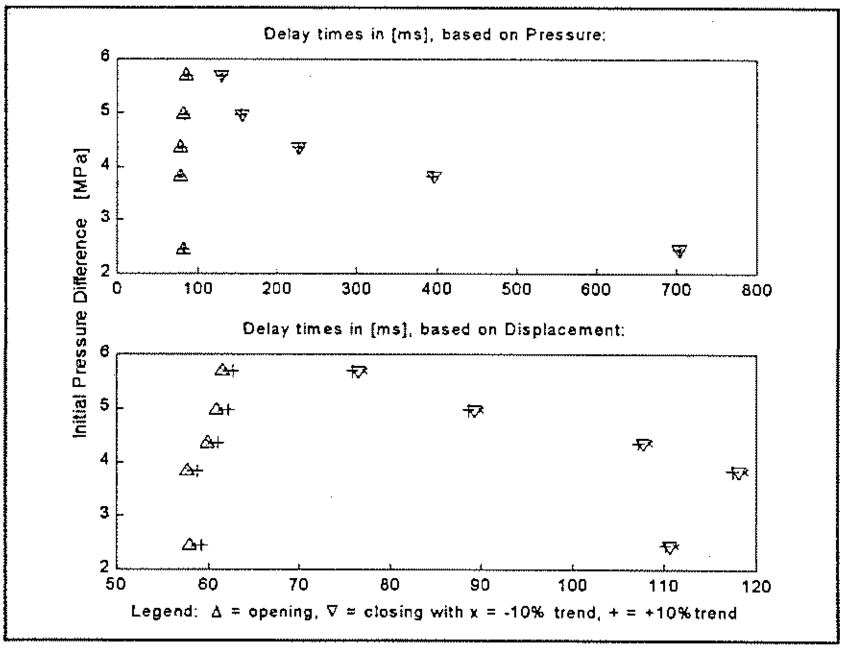

Figure A3.4.4 Pilot valve spring stiffness

Pilot Valve Spring Inital Displacement							
Run: 10+11	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.5	Opening						
Displacement	0.14	2.41	0.12	2.25	0.07	2.12	2.406
Pressure A	0.12	1.75	0.09	1.73	0.05	1.53	1.754
	Closing						
Displacement	0.48	-0.48	0.52	-0.45	0.75	-0.65	0.754
Pressure A	0.04	-0.03	0.24	-0.17	0.43	-0.40	0.433
	Steady State						
Displacement	-0.03	-0.02	0.01	-0.01	-0.00	-0.01	0.031
Pressure A	0.09	0.48	-0.01	0.06	0.01	0.01	0.482

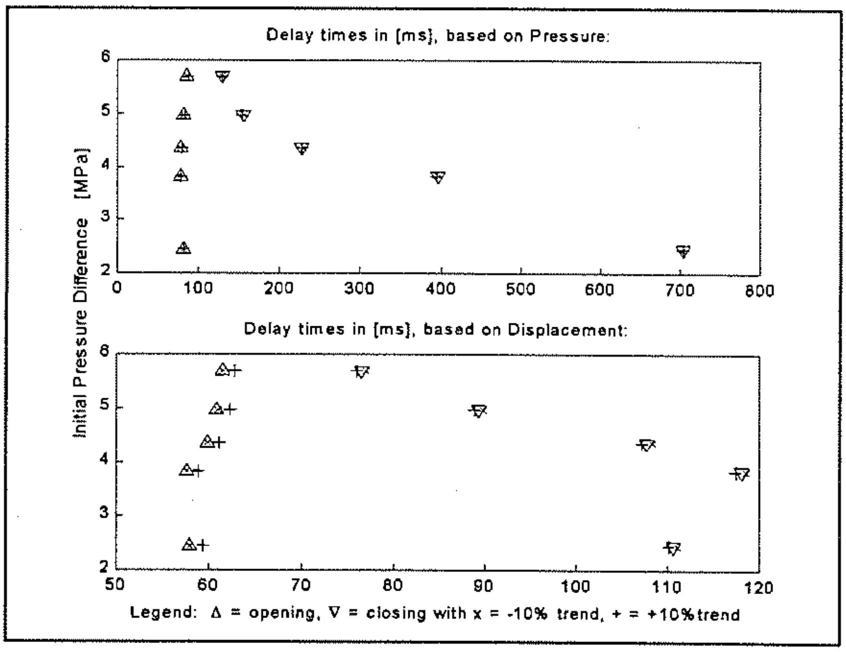

Figure A3.4.5 Pilot valve spring initial displacement

Logic Element Poppet Mass							
Run:	30 MPa		80MPa		210MPa		|max|
12+13	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.6	Opening						
Displacement	1.26	1.27	1.18	1.18	1.06	1.07	**1.267**
Pressure A	0.89	0.89	0.90	0.89	0.77	0.77	**0.895**
	Closing						
Displacement	-0.06	-0.03	0.00	0.01	-0.01	0.00	**0.057**
Pressure A	0.02	0.04	0.01	0.02	-0.00	0.00	**0.035**
	Steady State						
Displacement	-0.03	-0.02	0.00	-0.00	-0.01	-0.00	**0.034**
Pressure A	0.28	0.31	0.03	0.03	0.01	0.01	**0.313**

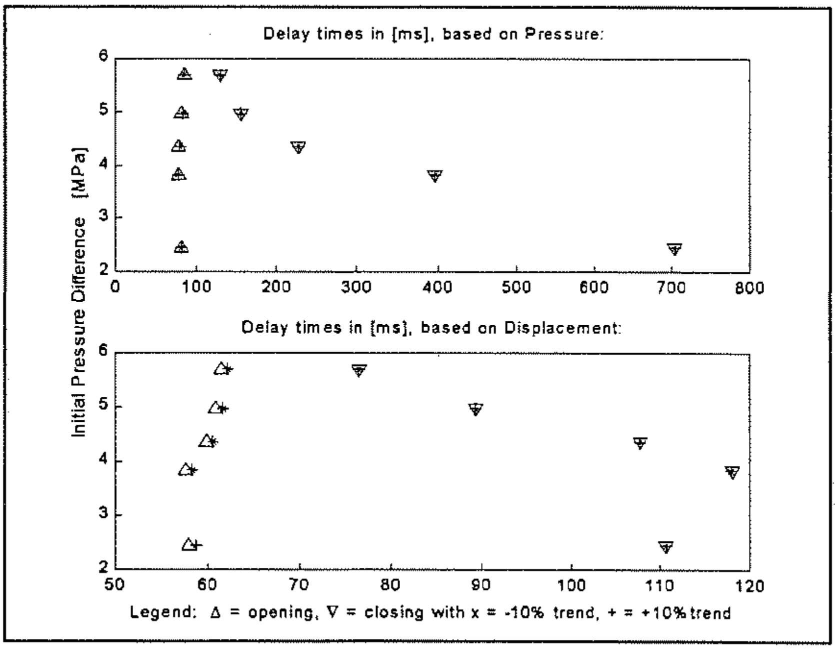

Figure A3.4.6 Logic element poppet mass

Logic Element Viscous Friction							
Run: 14+15 Fig A3.4.7	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
	Opening						
Displacement	0.77	1.67	0.95	1.42	0.85	1.28	**1.672**
Pressure A	0.77	1.00	0.77	1.02	0.61	0.93	**1.017**
	Closing						
Displacement	-1.27	1.11	-0.91	0.92	-0.57	0.58	**1.268**
Pressure A	-0.07	0.10	-0.31	0.36	-0.24	0.23	**0.364**
	Steady State						
Displacement	0.07	-0.22	0.36	-0.34	0.32	-0.33	**0.356**
Pressure A	0.19	0.65	-0.48	0.52	-0.38	0.40	**0.652**

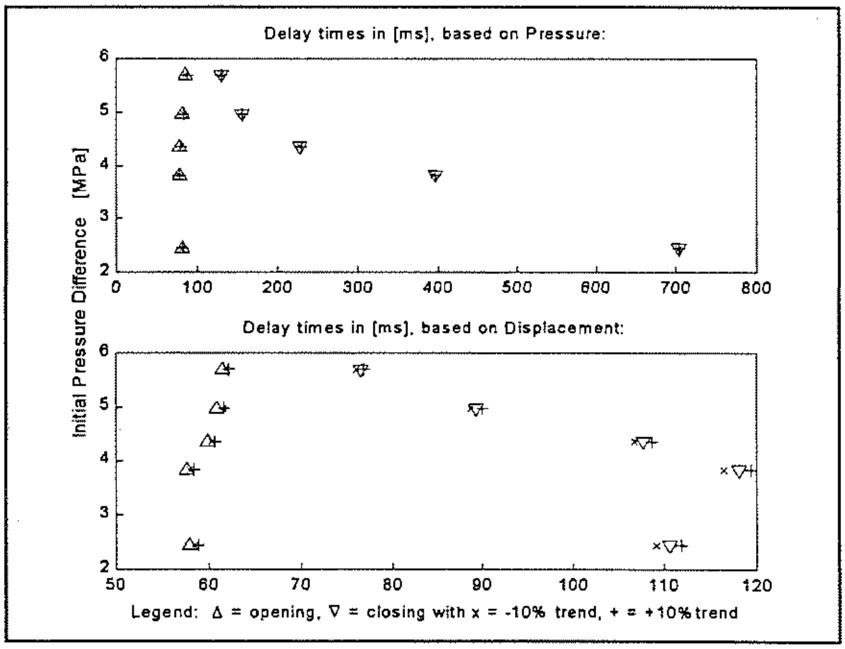

Figure A3.4.7 Logic element viscous friction

Logic Element Spring Stiffness							
Run:	30 MPa		80MPa		210MPa		|max|
16+17	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.8	Opening						
Displacement	1.39	1.12	1.31	1.06	1.13	1.00	**1.388**
Pressure A	0.88	0.90	0.88	0.91	0.76	0.79	**0.907**
	Closing						
Displacement	0.37	-0.44	0.42	-0.40	0.19	-0.20	**0.444**
Pressure A	-0.01	-0.01	0.21	-0.16	0.11	-0.11	**0.206**
	Steady State						
Displacement	0.19	-0.26	0.18	-0.17	0.10	-0.11	**0.261**
Pressure A	0.02	0.59	-0.24	0.29	-0.12	0.14	**0.586**

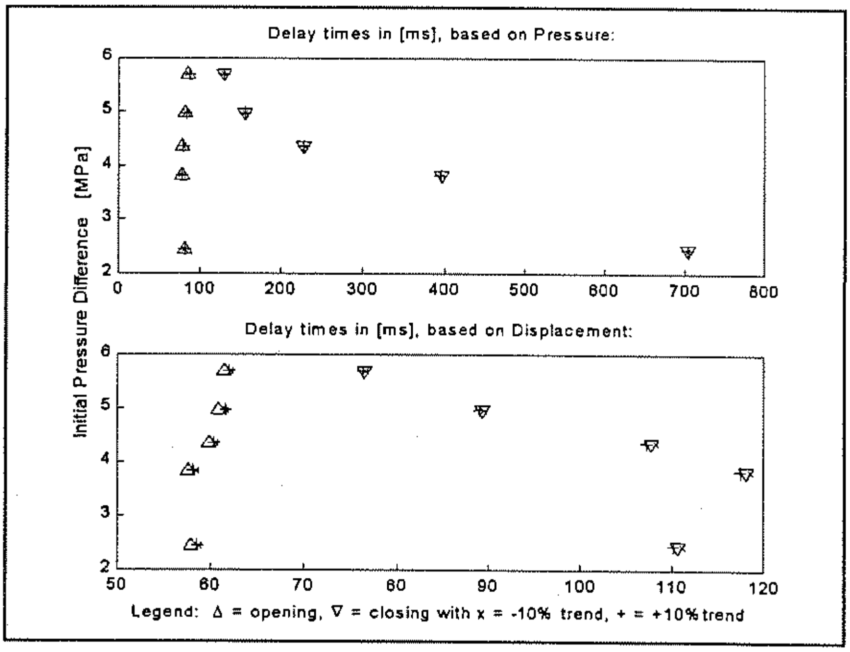

Figure A3.4.8 Logic element spring stiffness

Logic Element Initial Spring Force							
Run:	30 MPa		80MPa		210MPa		|max|
18+19	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.9	**Opening**						
Displacement	2.65	-0.17	1.78	0.38	1.36	0.79	**2.655**
Pressure A	0.78	1.00	0.75	1.03	0.63	0.91	**1.030**
	Closing						
Displacement	7.01	-5.96	4.18	-3.82	1.51	-1.43	**7.011**
Pressure A	0.71	-1.24	1.86	-1.63	0.82	-0.77	**1.857**
	Steady State						
Displacement	2.62	-2.80	1.19	-1.35	0.66	-0.66	**2.801**
Pressure A	-3.52	4.62	-1.69	2.06	-0.78	0.81	**4.621**

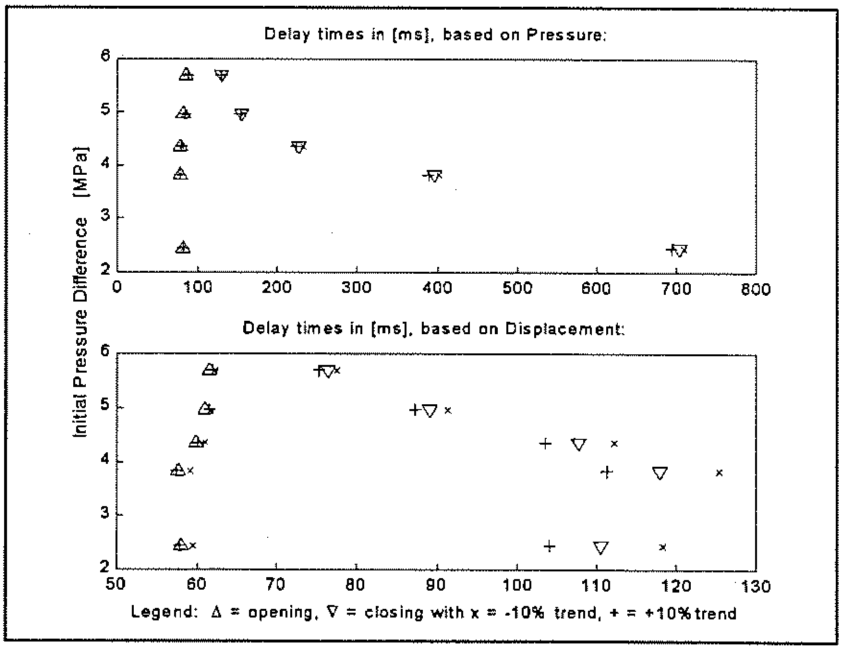

Figure A3.4.9 Logic element spring initial force

Logic Element Control Chamber Diameter							
Run:	30 MPa		80MPa		210MPa		|max|
20+21	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.10	Opening						
Displacement	-22.64	-0.55	-17.93	-0.07	-9.11	0.14	**22.635**
Pressure A	-6.66	0.31	-10.12	0.15	-13.68	-0.35	**13.682**
	Closing						
Displacement	-4.44	-0.23	19.12	1.31	42.54	2.07	**42.538**
Pressure A	-1.16	-0.05	6.51	0.59	21.02	1.14	**21.021**
	Steady State						
Displacement	-2.74	0.92	13.92	1.94	33.08	2.46	**33.082**
Pressure A	4.16	-0.63	-17.35	-2.72	-26.82	-2.84	**26.817**

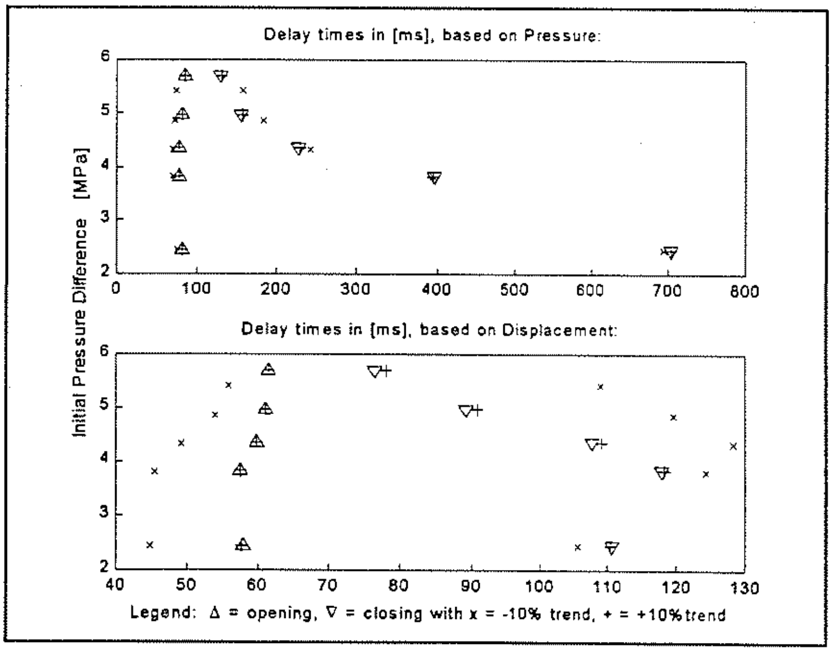

Figure A3.4.10 Logic element control chamber diameter

Check Valve #1 Cracking Pressure (flow from X to P)							
Run: 22+23 Fig A3.4.11	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
	Opening						
Displacement	-10.84	-25.57	-8.32	-8.36	-4.48	-4.51	**25.568**
Pressure A	-2.87	-8.46	-4.81	-4.84	-6.44	-6.46	**8.462**
	Closing						
Displacement	270.06	-58.34	110.20	235.58	42.74	52.77	**270.058**
Pressure A	39.25	-89.15	49.60	108.09	22.81	28.39	**108.089**
	Steady State						
Displacement	2.56	-17.43	9.67	9.68	16.83	16.83	**17.433**
Pressure A	-4.05	37.77	-12.93	-12.94	-16.25	-16.25	**37.770**

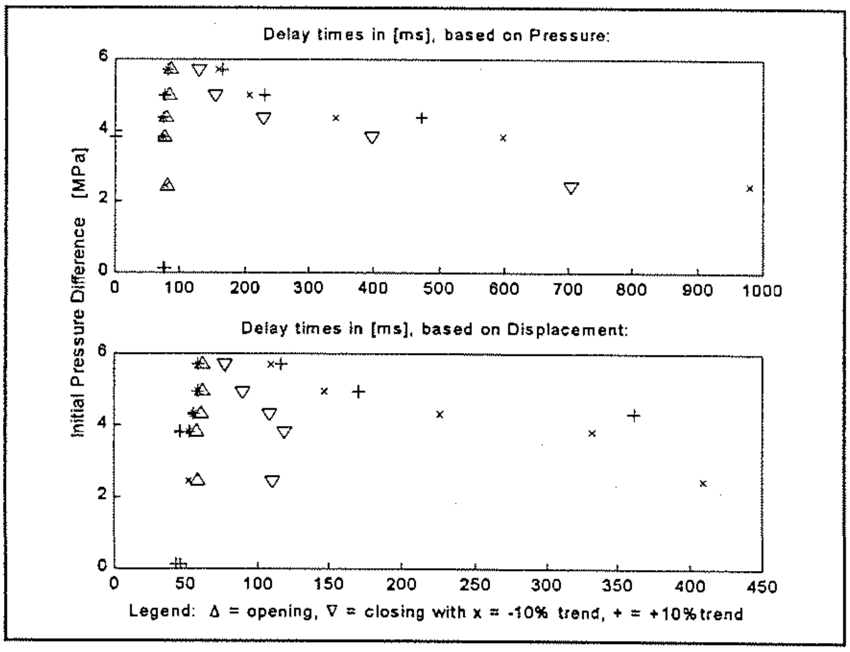

Figure A3.4.11 Check valve #1 cracking pressure

Check Valve #2 Cracking Pressure (flow from P to Y)							
Run:	30 MPa		80MPa		210MPa		|max|
24+25	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.12	Opening						
Displacement	-10.66	-10.21	-8.15	-8.21	-4.09	-4.69	10.663
Pressure A	-2.72	-2.50	-4.85	-4.53	-6.57	-6.18	6.565
	Closing						
Displacement	-1.76	-3.04	7.86	6.26	17.96	16.18	17.963
Pressure A	-0.56	-0.68	3.18	2.54	9.56	8.51	9.563
	Steady State						
Displacement	3.38	1.89	10.47	8.84	17.81	15.87	17.807
Pressure A	-5.17	-2.73	-13.76	-12.08	-17.00	-15.50	17.002

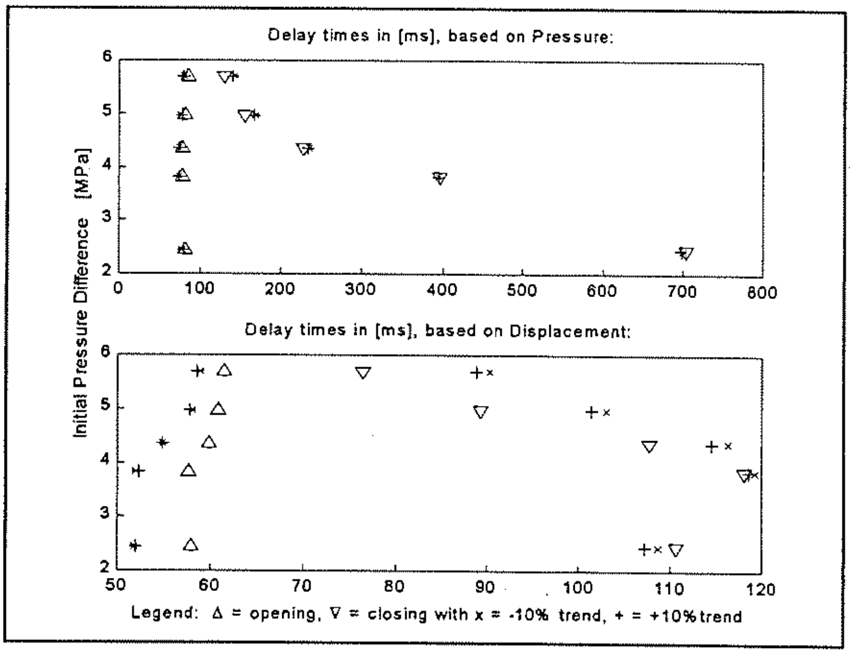

Figure A3.4.12 Check valve #2 cracking pressure

Damper Pressure Drop Gain							
Run: 26+27	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.13	Opening						
Displacement	-8.78	-11.84	-6.85	-9.41	-3.81	-4.90	**11.841**
Pressure A	-1.86	-3.68	-3.82	-5.43	-5.58	-7.08	**7.083**
	Closing						
Displacement	-5.38	0.57	3.76	10.24	13.90	20.10	**20.098**
Pressure A	-9.84	8.42	-3.29	10.59	2.81	15.40	**15.402**
	Steady State						
Displacement	-1.07	6.08	5.67	13.17	12.92	20.52	**20.524**
Pressure A	1.16	-8.33	-8.79	-16.39	-13.42	-18.76	**18.764**

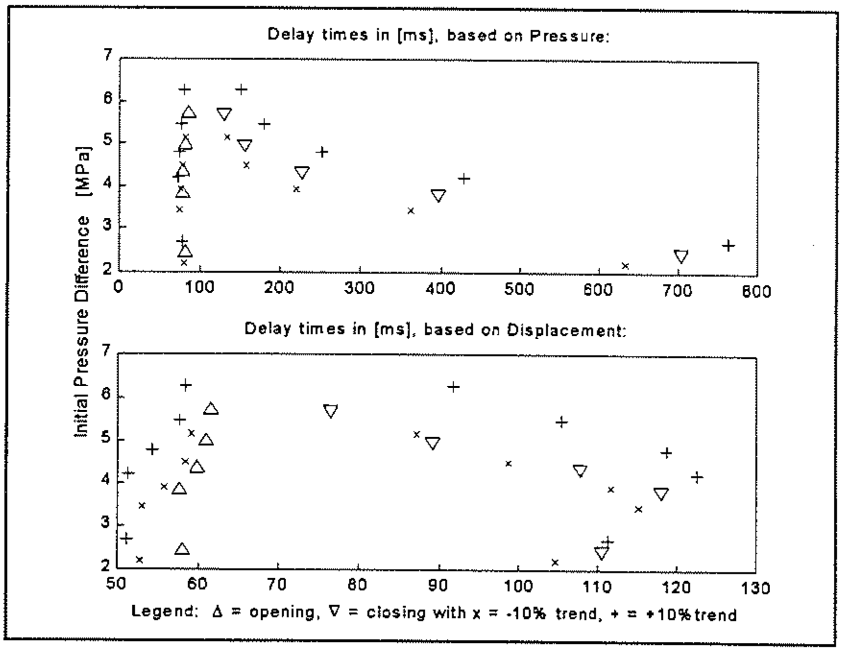

Figure A3.4.13 Damper pressure drop gain

Drain Elbow Diameter							
Run: 28+29	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.14	Opening						
Displacement	-10.52	-11.10	-8.16	-9.96	-4.39	-5.40	**11.101**
Pressure A	-2.63	-2.14	-4.69	-4.78	-6.37	-6.21	**6.372**
	Closing						
Displacement	-2.53	-3.43	7.09	4.23	17.06	13.11	**17.064**
Pressure A	-0.64	-0.79	2.83	1.50	9.03	6.42	**9.033**
	Steady State						
Displacement	2.50	1.37	9.69	6.35	16.83	14.03	**16.834**
Pressure A	-3.99	-3.50	-12.93	-14.10	-16.25	-23.72	**23.717**

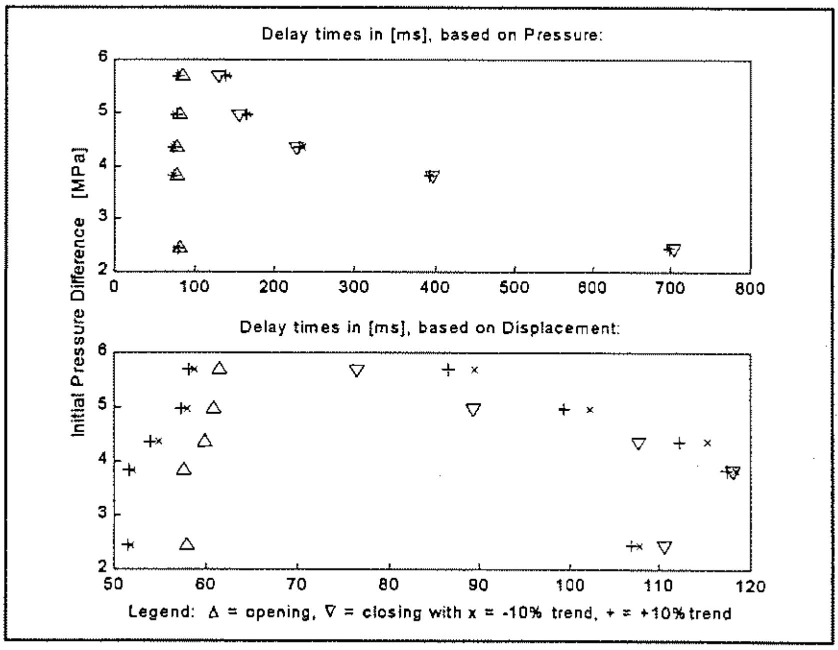

Figure A3.4.14 Drain elbow diameter

Test-Bench Quick Coupler Diameter							
Run: 30+31	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.15	Opening						
Displacement	-10.29	-11.19	-8.32	-9.77	-5.07	-4.97	11.194
Pressure A	-3.39	-1.88	-4.52	-4.34	-4.85	-7.07	7.068
	Closing						
Displacement	-2.95	-3.19	4.94	5.78	12.40	15.99	15.989
Pressure A	-0.85	-1.04	1.80	2.24	6.62	7.94	7.940
	Steady State						
Displacement	2.01	1.73	7.41	7.99	13.08	16.41	16.414
Pressure A	-3.62	-3.21	-13.37	-14.09	-19.24	-21.99	21.995

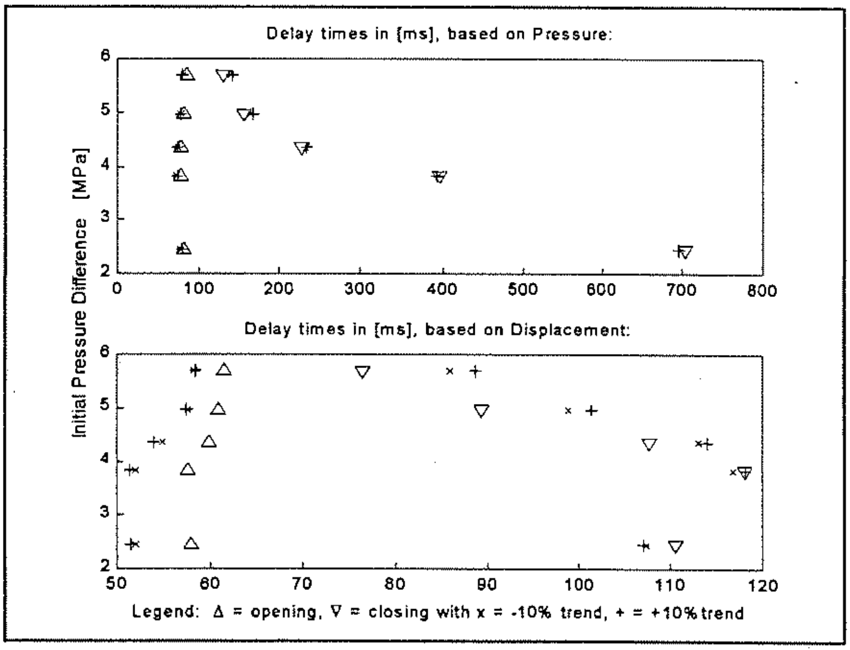

Figure A3.4.15 Test-Bench quick coupler diameter

Test-Bench Rubber Hose Stiffness							
Run: 32+33	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.16	Opening						
Displacement	-10.19	-11.36	-8.26	-10.10	-3.90	-5.99	**11.363**
Pressure A	-0.46	-3.81	-2.28	-6.67	-3.56	-8.52	**8.522**
	Closing						
Displacement	-1.56	-4.45	7.49	3.47	16.27	13.00	**16.270**
Pressure A	6.15	-6.69	7.48	-1.94	11.91	3.71	**11.911**
	Steady State						
Displacement	3.32	0.68	9.62	6.00	16.68	13.66	**16.680**
Pressure A	-6.55	-1.85	-16.41	-11.68	-22.11	-19.71	**22.111**

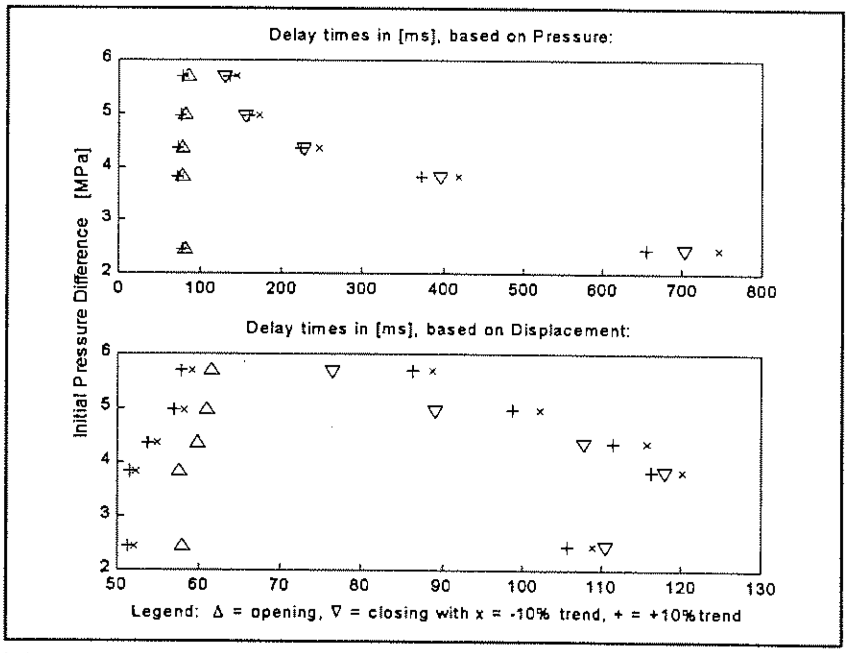

Figure A3.4.16 Test bench hose stiffness

Oil Bulk Modulus							
Run: 34+35	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.17	Opening						
Displacement	-4.68	-5.26	-3.66	-4.32	-2.98	-3.67	5.265
Pressure A	1.02	-0.24	1.80	0.32	3.21	0.89	3.214
	Closing						
Displacement	-14.93	-16.00	-12.69	-13.73	-10.89	-11.48	16.005
Pressure A	0.50	-4.84	-3.94	-7.42	-4.46	-7.46	7.462
	Steady State						
Displacement	-1.70	-2.79	1.48	0.52	1.99	1.33	2.785
Pressure A	13.36	15.25	8.50	10.05	10.51	11.39	15.247

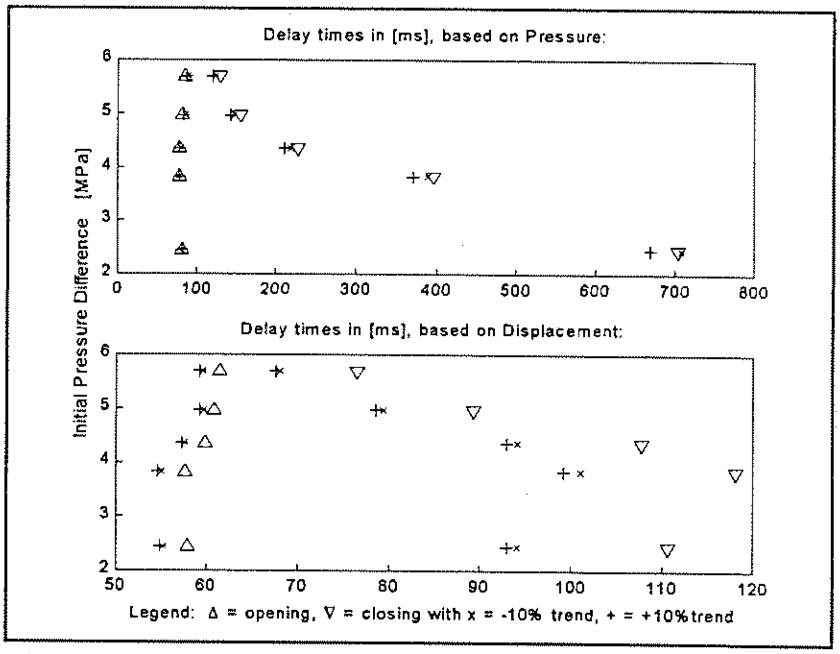

Figure A3.4.17 Oil bulk modulus

Oil Kinematic Viscosity							
Run: 36+37	30 MPa		80MPa		210MPa		|max|
	-10%	10%	-10%	10%	-10%	10%	
Fig A3.4.18	Opening						
Displacement	-5.92	-4.24	-4.54	-3.55	-3.34	-3.31	5.925
Pressure A	0.29	0.39	1.25	0.89	1.86	1.90	1.903
	Closing						
Displacement	-18.15	-13.01	-14.57	-12.06	-12.19	-10.27	18.146
Pressure A	-2.39	-1.65	-6.27	-5.57	-6.33	-5.88	6.329
	Steady State						
Displacement	-4.38	-0.48	0.53	1.37	1.90	1.39	4.379
Pressure A	7.97	19.42	4.12	14.41	9.90	12.09	19.424

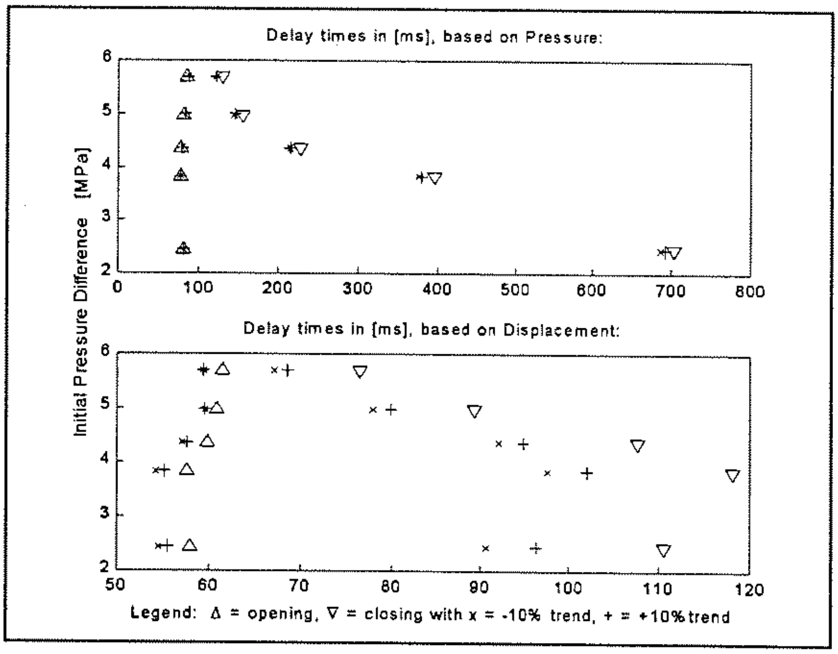

Figure A3.4.18 Oil kinematic viscosity

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Instrumentation A 4.1

The purpose of this annexure is to document the measurement system and instrumentation used and to show calibration data to establish confidence in the experimental work conducted and for future reference.

Whenever possible, all systems were switched on and left for at least 30 minutes to reach thermal stability. This is particularly intended to stabilize the resistors used in pressure and displacement measurements to convert a sensor mA signal to measured Volts. Test bench oil was also allowed to circulate for thermal stability.

A 4.1.1 Pressure sensors and convertor

With the kind permission of Ermetek three pressure transducers were obtained (Type WIKA Tronic). The 4-20mA signal is converted to volts using a custom made resistance box with the measuring circuit shown in figure A4.1.1. The conversion box was tested by measuring the zero offset of one sensor through each channel. An offset of no more than 1mV was found. To simplify the administration, sensors are marked P1, P2 and P3 for the purpose of this study. The 4-20mA sensor protocol is particularly practical and easy to use. The sensor regulates the current flow, independent of the input voltage. This has the result that the measuring system is insensitive to input voltages and voltage drop in the sensor wires cannot play a role. The 4mA signal is used as a zero in order to supply power to the sensor at all times. The only component needed to convert the 4-20mA signal to a voltage output is an accurate resistor. The voltage reading is converted to engineering units using equation A4.1.1.

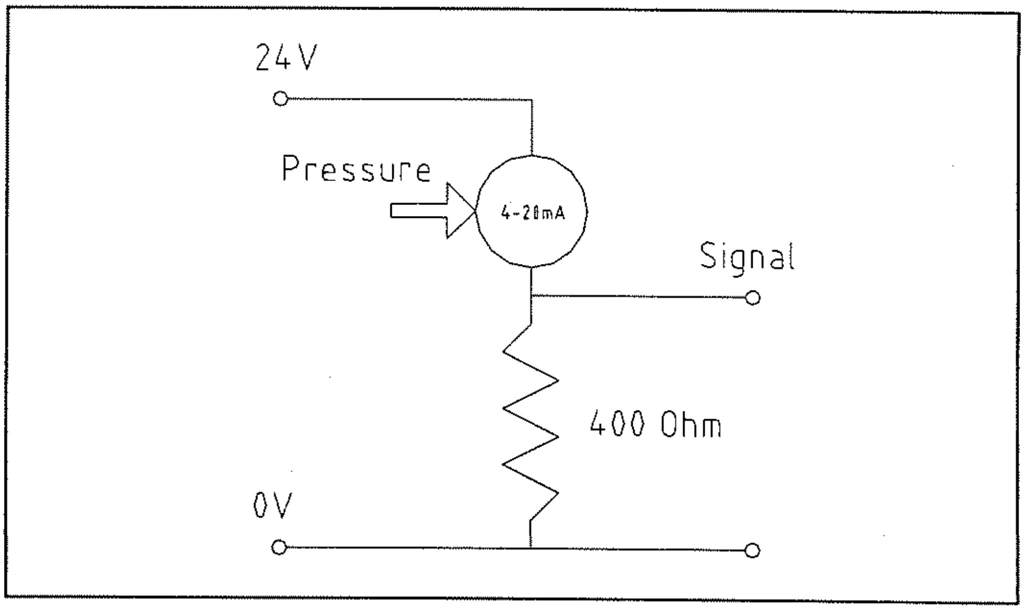

Figure A4.1.1 Circuit diagram for the conversion of mA to Volts.

At 4mA the signal voltage is approximately 1.6V and at FSD (Full Scale Deflection, that is 20mA) the signal voltage is 8V.

Eq A4.1.1
$$[\text{MPa}] = (\text{Signal} - \text{Zero}) \cdot \frac{25}{6.4}$$

The value of 25 (in eq A4.1.1) is an arbitrary scale factor. In this case it refers to 25MPa at FSD.

To establish confidence in the sensors and to verify the unit conversion technique, sensor zero readings and deadweight testing were done. Zero readings were done by putting sensors to atmosphere and measuring signal voltage readings with a multimeter. Deadweight tests were done, but after examination of the results, the deadweight tester proved faulty.

The sensors were consequently checked against an accurate reference bourdon tube pressure sensor. The results are not intended to provide calibration factors, but merely to confirm the accuracy and linearity. Many readings at different pressures were taken and the linearity and accuracy were established (not shown). Accuracy of the pressure transducers at low values of full scale deflection is not known.

Sensor	Range (Bar)	Zero (Volt)
P1	250	1.605
P2	250	1.59
P3	400	1.591

A 4.1.2 Flowrate

In this study a positive displacement flowmeter (Named VS1) and two turbine flowmeters fitted to the test bench were used. All three flowmeter used were calibrated against a master flowmeter at Hytec (Kempton park). This flowmeter was imported and calibrated in Germany. Unfortunately no calibration documentation are available.

A4.1.2.1 Positive displacement flowmeter (VS1)

The VS1 flowmeter (manufactured by VSE GmbH) is mounted on a sub-plate with hydraulic connection ports. The display unit is compatible with a number of VSE type flowmeters and had been altered (by the University of Pretoria, LGI) to give a voltage reading proportional to the displayed value. In the specific combination used the displayed flow is exactly 5 times lower than true flow through the meter. From calibration it was also determined that the voltage output do not match the displayed value. (Figure A4.1.2) A correction factor is determined for use in data analysis later on. (Equipment serial numbers in par A4.1.6) The VS1 flowmeter is shown in photograph 8.

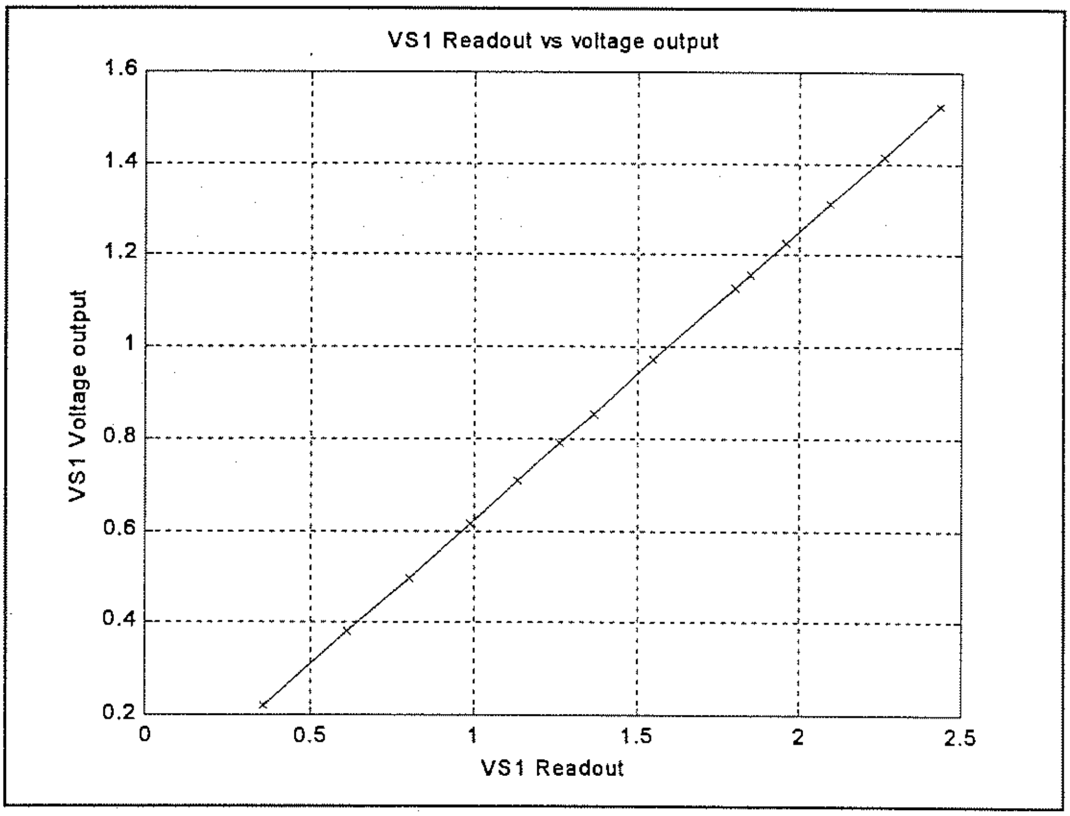

Figure A3.1.2 VS1 Flowmeter output voltage calibration

A4.1.2.2 Turbine flow meters

The LGI test bench is fitted with Flo-check turbine flowmeters on each of the two 45LPM pumps. These units are matched to digital display units in the control panel. Indicated on the meters is factory calibrated frequency output versus flow, as indicated in the table:

Sensor	**Flow at 100 Hz**	**Flow at 800 Hz**
Turbine: Pump A	4.7 LPM	37.3 LPM
Turbine: Pump B	5.2 LPM	41.2 LPM

It is possible that the incorrect turbine units were originally installed on the test bench. The digital readout A is marked for use with sensor #31502, but sensor #31503 is installed on the test-bench. Since the units were recalibrated, this mismatch does not affect the readings taken.

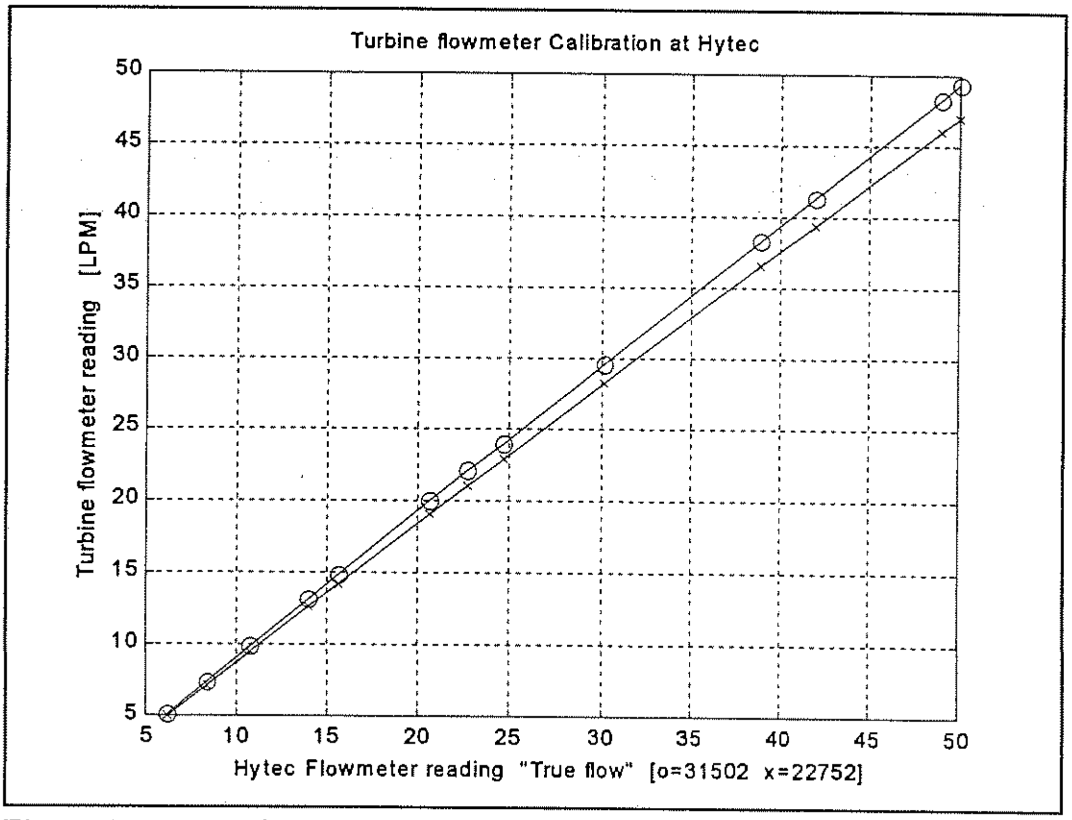

Figure A4.1.3 Turbine flowmeter calibration

A4.1.2.3 Determination of correction factors

Using the graphs shown above, a least-squares linear regression is fitted using the MATLAB polyfit procedure. Parameters for the equation y = mx + c is shown in the table below:

Sensor	m	C
VS1	0.63	-0.01
Turbine 31502	0.9978	-0.5483
Turbine 22752	0.9464	-0.3641

The true flow can be calculated with:
For VS1 flowmeter:

Display = voltoutput / m - C

eq A4.1.2 **And**: Display x 5 = TrueFlow

Thus: *TrueFlow* = (*voltoutput* / m - C) x 5

For turbine flowmeters:

eq A4.1.3 *TrueFlow* = *Reading* / m - C

A 4.1.3 Poppet displacement

In order to measure the logic element poppet displacement, a linear resistance transducer was used, fitted to a custom manifold block. A voltage of approximately 24V is applied across the resistor. The wiper output is scaled with a 1K and 2K ohm voltage divider to limit the maximum voltage output. This is necessary since the Modacs data acquisition system has a maximum range of 10V. It is, however, difficult to guarantee the applied voltage value (a voltage reference circuit will have to be built), but it is known that the maximum poppet movement is 8mm. This can be used to determine the displacement as follows:

eq A4.1.4 (MaxV - MinV) / 8 = [V/mm]
With MaxV and MinV obtained from the measured data.

With the [V/mm] factor obtained, a displacement voltage measurement can be converted to a displacement in millimeters.

A 4.1.4 Solenoid voltage

In order to define an exact starting point for time delay determination, the time of solenoid voltage application is recorded. Since any normal switch has a bounce period where the contacts rapidly opens and closes (for about 5ms), a switch debounce circuit has to be used. The following circuit was taken from Elektra Elektor project 914022 [Jeukendruk 1991] and adapted to drive power transistors. The 24V solenoid voltage is measured with the aid of a voltage divider, since the Modacs data acquisition system is only capable of measuring 10V maximum. The debounce circuit was evaluated with a digital storage oscilloscope. It was found to eliminate more or less 80% of the switch bounce. The remaining bounce is less than 1ms.

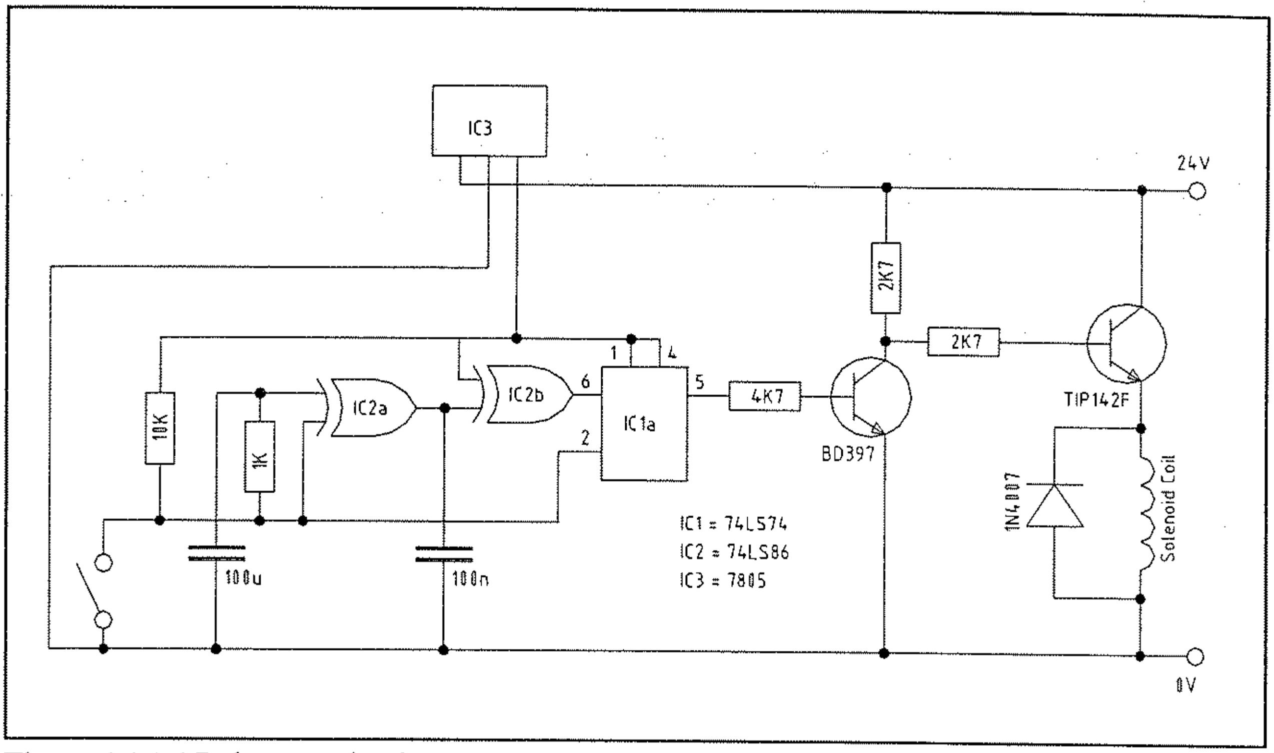

Figure A4.1.4 Debounce circuit

A 4.1.5 Data acquisition

Modacs is a high speed, high accuracy data acquisition system. It consists of an analogue / digital conversion unit with internal hard disk drive. An external notebook computer controls the data acquisition process. After completion of tests, the data is transferred via a network connection to a PC where a conversion program writes the data to MATLAB legible format. The unit has 12 analogue inputs with a maximum range of 10V DC. The maximum sample frequency is 4 kHz per channel. After some initial experimentation it was decided to use a 2 kHz sample frequency (0.5 ms sample interval). This provided enough detail of the transient behaviour without unnecessary noise. (Some experiments were conducted with a 1 kHz sample rate.) The Modacs is shown in photograph 3.

A 4.1.6 Miscellaneous equipment and serial numbers

Type	Model name / Type	Serial number
Dual laboratory power supply	Coutant LC60	IN-017
Digital storage oscilloscope	Philips PM3335	OC-002
Multimeter	Fluke 83	101134
Laboratory balance	Mettler	
Needle valve	Bosh	0-811-300-001
Linear potentiometer	Midori: CSS-20-1	-

Pressure sensor	WIKA Tronic 250Bar	2051867 = **P1**
Pressure sensor	WIKA Tronic 250Bar	2051872 = **P2**
Pressure sensor	WIKA Tronic 250Bar	1071699 = **P3**
4Ch, 4-20mA Converter box for pressure sensors	Custom Built	GS1003
Positive displacement flow sensor	VSE (GmbH) VS1 GP012V	120/93004
Positive displacement flow indicator (readout)	VSE (GmbH) MF1-3-220-5-1	436900
Modacs	Mecalc	460656
Laptop	IBM ThinkPad 365X	478829
Pump A flow control card	QV60-RGC1	-
Pump A pressure control card	PV60-RGC1	-
Pump B flow control card	4/3WV-NG10	-
Pump A pressure control card	B830 303 035	-
Flow turbine A	Flo-Teck FSC-500-6H	31503-R
Flow indicator A	Flo-Teck DRM 100	31364-AB
Flow turbine B	Flo-Teck FSC-500-6H	22752-R
Flow indicator B	Flo-Teck DRM 100	21785-AB

90 LPM Test Bench — A 4.2

This annexure contains information regarding the 90 LPM test bench, with a schematic of one supply line shown in figure A4.2.1.

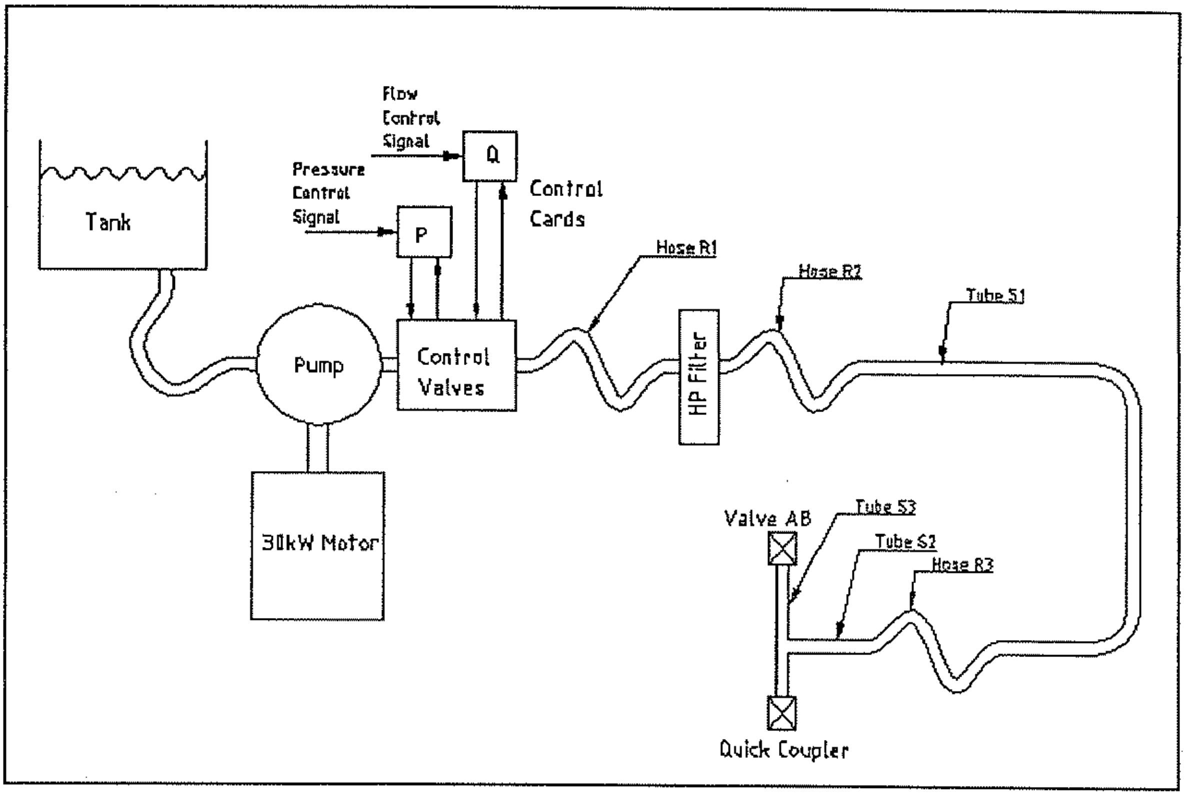

Figure A4.2.1 Schematic layout of one test bench pump and supply hoses

A4.2.1 Work done on the 90 LPM test bench

The test bench was in dire need of repair and upgrading in order to fulfill the tasks required and to provide future usefulness. The following tasks are noted to record the status of the test bench as used in this work:

1. *Pump and control-cards testing*. The test bench had not been used recently. In order not to cause any potential damage and to establish the test bench condition, the two main pumps and their respective control cards were sent to Hyflo Pty (Ltd.) for testing. The pumps tested 100%, but two of the four control cards were found to be defective. Two new control cards and new filter elements were purchased.
2. *Pipe reinstallation.* The test bench is capable of controlling and delivering the A and B flows individually. Only one of the supply lines was found to be installed. A second hydraulic line was installed from the main pump to the user console.
3. *Flush-line circuit.* The circulation (flush) pump was refitted. After careful inspection it was found that the original flush-line circuit was incorrectly installed. The flush circuit

would not have been able to function. This fault was repaired.

4. *Rewiring.* With the new control cards, and the current state of wiring, it was decided to rewire the control panel. The power supply transformer was also found to be insufficient and replaced. Currently, the power supply smoothing capacitors are sub-standard, but provide adequate performance. Future replacement is suggested.
5. *Diagrams.* The electrical circuit diagrams were updated.
6. *Calibration.* The test bench is fitted with turbine flowmeters. These sensors were calibrated at Hytec Pty (Ltd). Results of this calibration are shown in paragraph A4.1.2.
7. Occasionally it was found that the turbine flowmeters showed incorrect readings. To find the fault, two BNC tap points were installed in the turbine sensor signal lines for examination on an oscilloscope. This installation solved the problem. Improper grounding was the likely cause.
8. The test bench uses quick couplers at the user console to aid in quick experimental setups. This works well, but the drain line resistance and inertia can influence measurements drastically. From experiments conducted, the drain line resistance (including one quick coupler) was measured and is shown in figure A4.2.2.

A4.2.2 Suggested future work to be done on the test bench

1. The control cards' gain and zero points are not precisely set up. New control potentiometers and voltmeters in the control panel should be installed before attempting to fine-tune these values.
2. New smoothing capacitors for the power supply are necessary.
3. One of the master dial pressure gauges was never installed and is available for fitment.
4. The hydraulic reservoir tank should be opened, cleaned, checked for leakage and sealed properly to assure clean oil.
5. The filter pressure switches and thermostat indicator lights are not wired. For prolonged operation the heat exchanger should be tested for proper cooling of the oil.
6. The step response of the test bench should give valuable information with which to create future models. It should be possible to measure step response if a very fast acting proportional valve is fitted to the test bench and switched. Another method of obtaining similar data might be to close the test bench supply port at the user console and apply a step input to the control card inputs. It should be noted that the response obtained will be for a zero flow rate situation.

A 4.2.3 Drain line resistance

The drain line returns oil to the test bench reservoir. During experiments a large flow resistance was measured in the drain line, with a large volume of oil that has to be accelerated. To overcome this problem, oil was drained directly into a 210*l* drum, before being returned to the main reservoir. For reference the drain line resistance is given in figure 4.2.2.

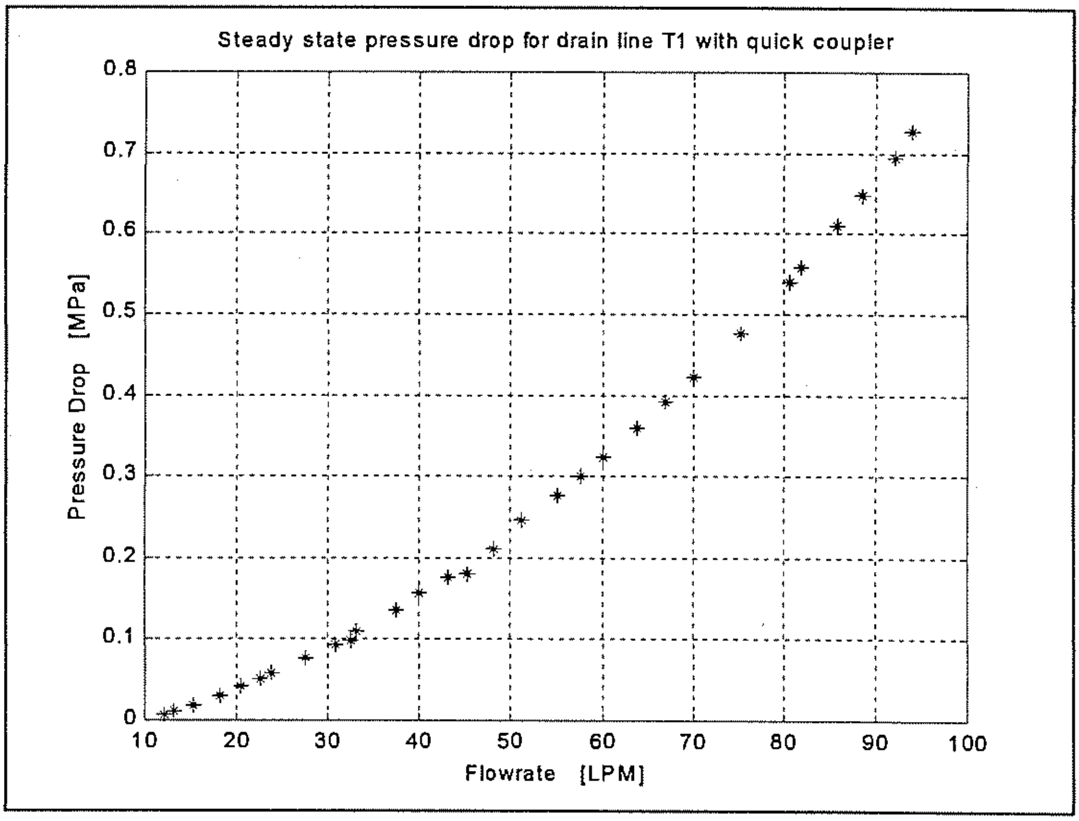

Figure A4.2.2 Test bench drain line steady state flow resistance

A 4.2.4 Test bench supply line volume

As mentioned throughout this document, the supply line caused several inaccuracies. The dimensions as measured and used in the AMESim models are given in the following table. (These dimensions are not accurately known, especially the pipe internal diameters that are only estimated, based on catalog data). Data regarding the drain line should ideally also be obtained and used, if a detailed model of the test bench is to be constructed.

Name	Material	Length [m] Pump A	Length [m] Pump B	Outer diameter [mm]	Internal diameter (Est.) [mm]
R1	Rubber	3.3	3.3	35	23
R2	Rubber	1	1	40	27
S1	Steel	5.2	5.6	30	24
R3	Rubber	0.5	0.5	40	27
S2	Steel	0.1	0.3	20	15
S3	Steel	0.6	0.6	20	15
HP Filter	Steel	0.3	0.4	100	80
	Total Volume	**6.2 Litre**	**6.9 Litre**		
	Total	**13.1 Litre**			

A 4.2.5 Ground loops

During the initial stages of the experimental work a severe ground loop problem was encountered. The problem was very elusive since the typical 50Hz signal was masked with other noise. When recording data, almost none of the dynamic performance could be seen under the noise signal. The problem could not be pinpointed. Finally, a 100V ac signal was measured on the data acquisition system casing (supposed to be grounded). This was attributed to seawater that had seeped into the electrical cables when they were previously used on a ship. New power cables and proper grounding solved the problem. (This paragraph serves as a personal reminder of the many hours spent in utter despair to obtain usable data.)

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Custom Test Equipment A 4.3

Several pieces of equipment were manufactured in order to complete the experimental work. The engineering drawings for most of these are given for reference.

A 4.3.1 CSS Filler plug
A 4.3.2 CSS Spacer
A 4.3.3 LC25 Stroke Limiter
A 4.3.4 Manifold CSS: Hytec drawing number A 120 7820 00, Job No. 650264
A 4.3.5 Threaded Plug for Manifold CSS: Drawing number A 320 7823 00
A 4.3.6 Adapter for Manifold CSS or WSE (original) Manifold: Drawing number A 220 7820 00

As mentioned in chapter 4, a special test block was manufactured to facilitate the dynamic measurement of the logic element poppet displacement and control circuit pressures. A comparison of the physical differences between the old (original manifold) and new WSE (manifold CSS) block can be made as follows:

1 **Mass of poppet:** In order to install the CSS displacement transducer, an aluminium spacer (A4.3.2) is inserted into the logic element poppet. It is kept in position by the logic element spring. The CSS transducer also adds some mass and slightly more friction to the logic element poppet.

2 **Spring stiffness:** With the CSS spacer installed, the logic element spring is compressed 1 mm more.

3 **Flow restrictions in block:** The block has much longer channels and more bends in them than the original block. The original block has about 40mm long channels with 2 bends. The new block has about 150mm channels and 3 bends per pilot valve (WSE) port. These ports are however quite large in diameter and the effect is ignored.

4 **Orifices:** The 1 mm protection orifices were not installed in the new block.

5 **CSS interference:** The CSS transducer has a collet on its tip. This collet can close off the logic element chamber flow, should the spacer be too short. Care should be taken when installing the spacer that the CSS shaft is guided into the tip of the spacer. The CSS sensor is hollow, and more oil is subjected to the control chamber pressure than with the original block. From simulation the effects of this volume is found to be small and the effect is ignored. In experiments without the CSS, it was replaced with an aluminium plug to compensate for the additional oil volume.

6 **More chance of air:** The new block has more channels, as mentioned. Most of them have drillings that are plugged. An air bubble could easily get trapped in the dead end of the drilling.

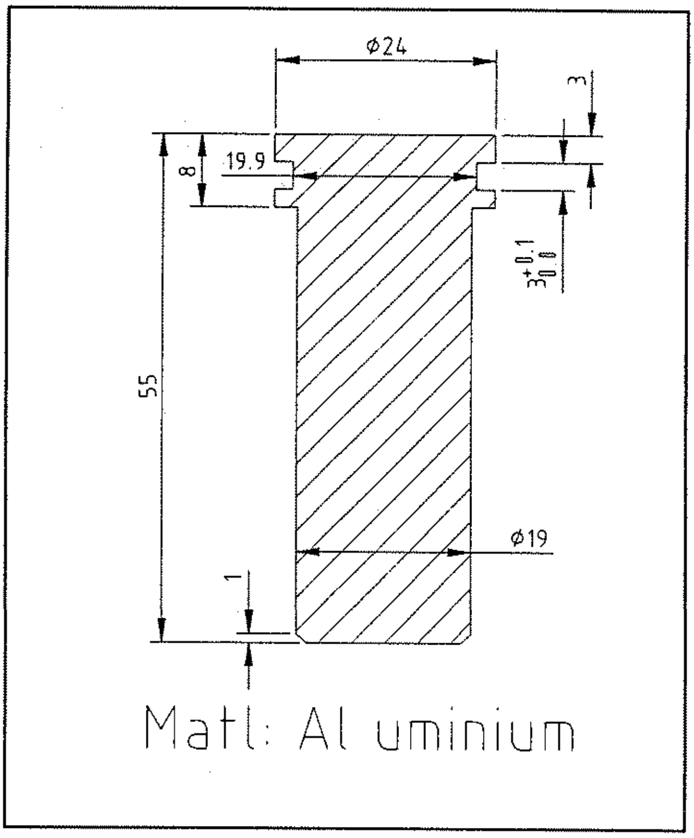


Figure A4.3.1 Plug used to fill CSS port

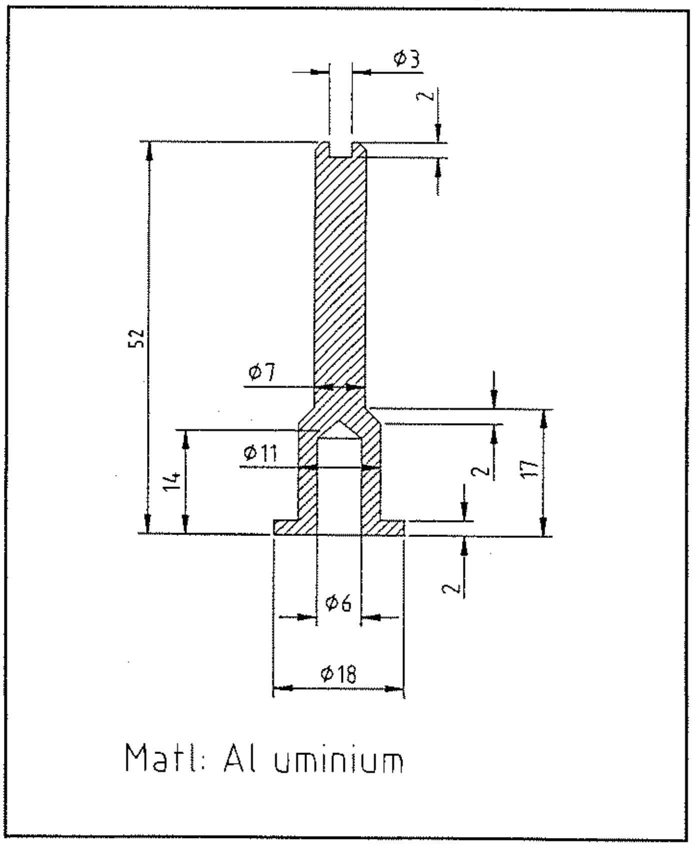


Figure A4.3.2 Spacer used to activate CSS sensor

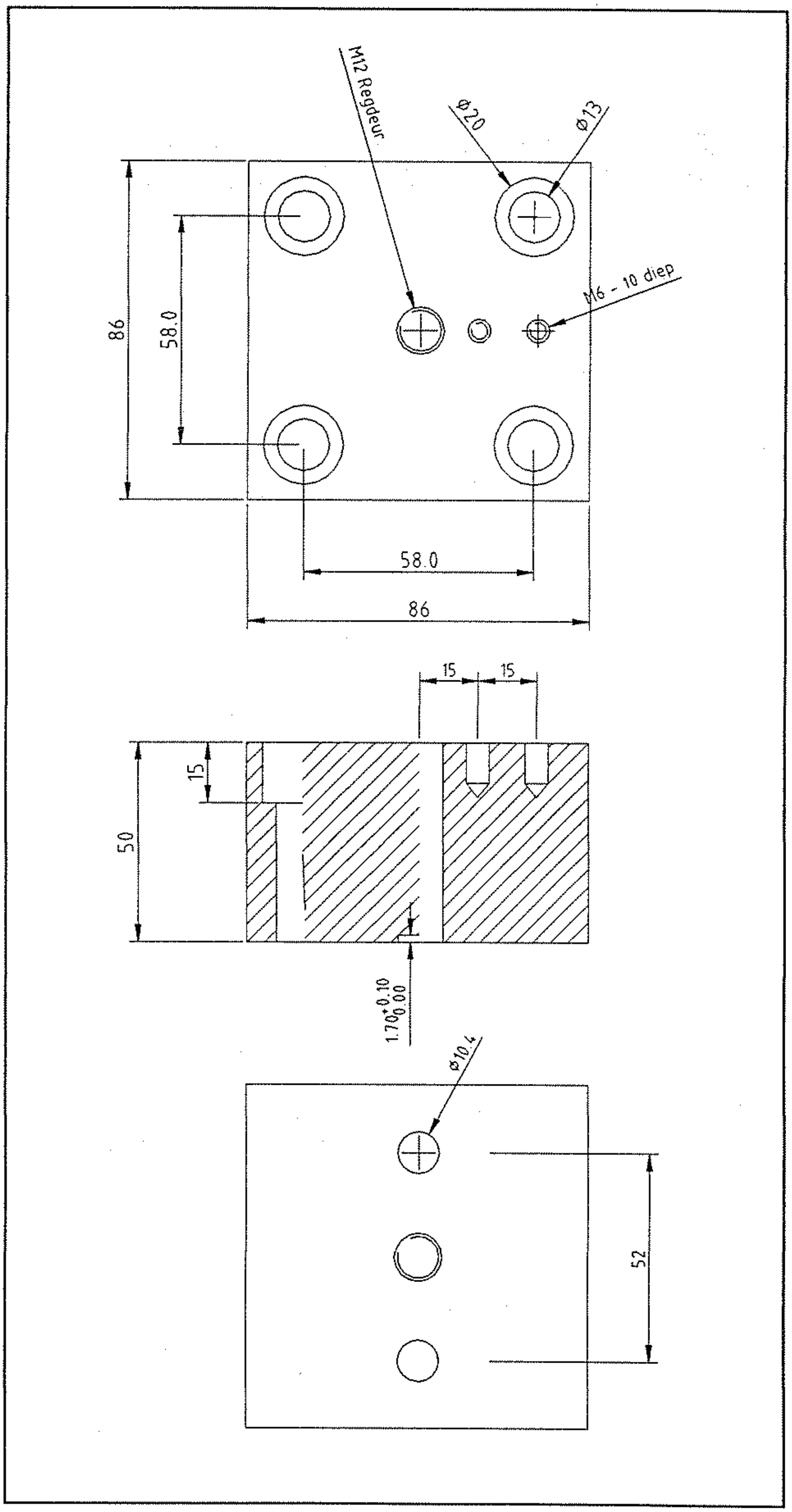
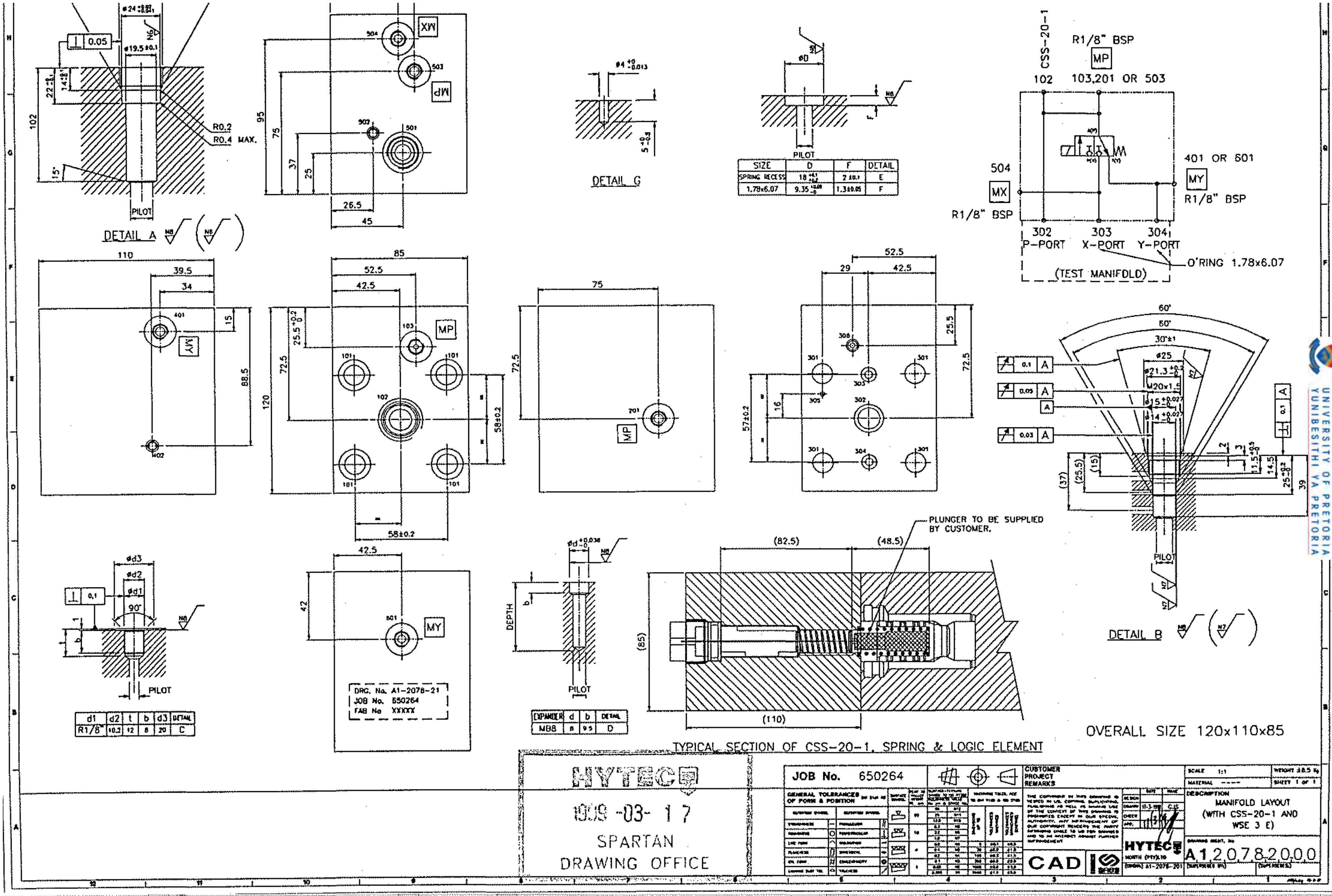
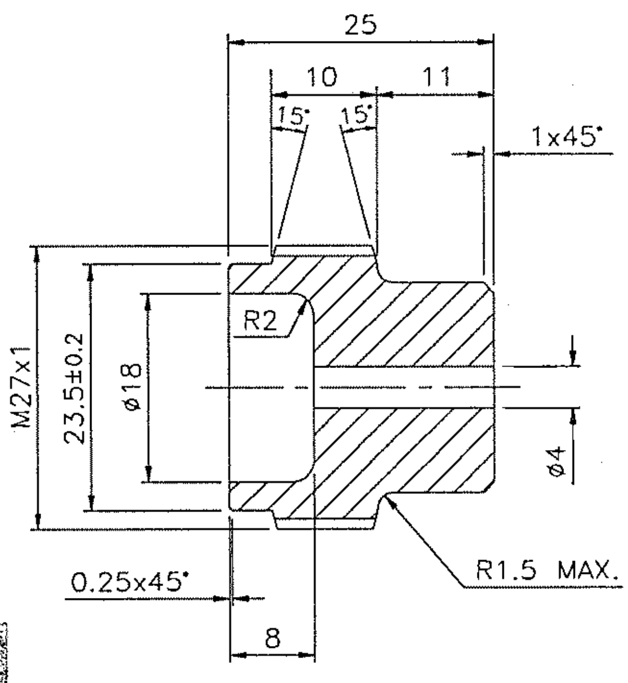
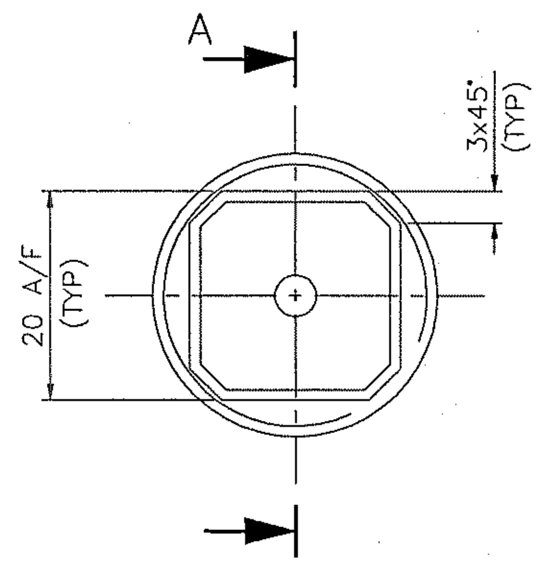


Figure A4.3.3 Stroke limiter manufactured for use on the LC25.


DETAIL A
DETAIL G
DETAIL B
R0.2
R0.4 MAX.
PILOT
SIZE | D | F | DETAIL
SPRING RECESS | 18 | 2 ±0.1 | E
1.78x6.07 | 9.35 | 1.3±0.05 | F
CSS-20-1
R1/8" BSP
MP
102
103,201 OR 503
504
MX
401 OR 601
MY
302 P-PORT
303 X-PORT
304 Y-PORT
O'RING 1.78x6.07
(TEST MANIFOLD)
PLUNGER TO BE SUPPLIED BY CUSTOMER.
d1 | d2 | t | b | d3 | DETAIL
R1/8" | 10.2 | 12 | 8 | 20 | C
DRG. No. A1-2078-21
JOB No. 650264
FAB No XXXXX
EXPANDER | d | b | DETAIL
MB8 | 8 | 9.5 | D
DEPTH
OVERALL SIZE 120x110x85
TYPICAL SECTION OF CSS-20-1, SPRING & LOGIC ELEMENT
HYTEC
1999-03-17
SPARTAN
DRAWING OFFICE
JOB No. 650264
CUSTOMER
PROJECT
REMARKS
GENERAL TOLERANCES OF FORM & POSITION
SCALE 1:1
MATERIAL ----
DESCRIPTION
MANIFOLD LAYOUT
(WITH CSS-20-1 AND
WSE 3 E)
HYTEC
CAD
A1 2078 2000



SECTION A–A



N8

NOTE:
1–REMOVE BURRS AND SHARP EDGES.

JOB No. 650264

CUSTOMER
PROJECT
REMARKS

SCALE	2:1	WEIGHT	-- Kg
MATERIAL	EN8 BAR	SHEET	1 OF 1

GENERAL TOLERANCES OF FORM & POSITION DIN 3141 R3

DEFINITION	SYMBOL	DEFINITION	SYMBOL
STRAIGHTNESS	—	PARALLELISM	//
ROUNDNESS	○	PERPENDICULAR	⊥
LINE FORM	⌒	INCLINATION	∠
PLANENESS	▱	SYMETRICAL	≡
CYL FORM	⌭	CONCENTRICITY	◎
LAMINAR SURF TOL	⌓	TRUENESS	↗

SURFACE SYMBOL	PEAK TO VALLEY HEIGHT Rt µm	SURFACE-TEXTURE SYMBOL TO ISO R1302 ROUGHNESS VALUE Ra µm	GRADE No.
▽	63	50	N12
		25	N11
		12.5	N10
▽▽	16	6.3	N9
		3.2	N8
		1.6	N7
▽▽▽	4	0.8	N6
		0.4	N5
		0.2	N4
▽▽▽▽	1	0.1	N3
		0.05	N2
		0.025	N1

MACHINING TOLER. ACC TO DIN 7168 & ISO 2768

DIMENSIONS UP TO	TOLERANCES MACHINED	TOLERANCES UNMACHINED (CASTING)
6	±0.1	±0.5
30	±0.2	±1.0
100	±0.3	±1.5
300	±0.5	±2.0
1000	±0.8	±3.0
2000	±1.2	±5.0

CAD SABS

	DATE	NAME
DESIGN		
DRAWN	23-02-1999	ECD
CHECK	24-02-1999	GJS
APP.	25-02-1999	GJS

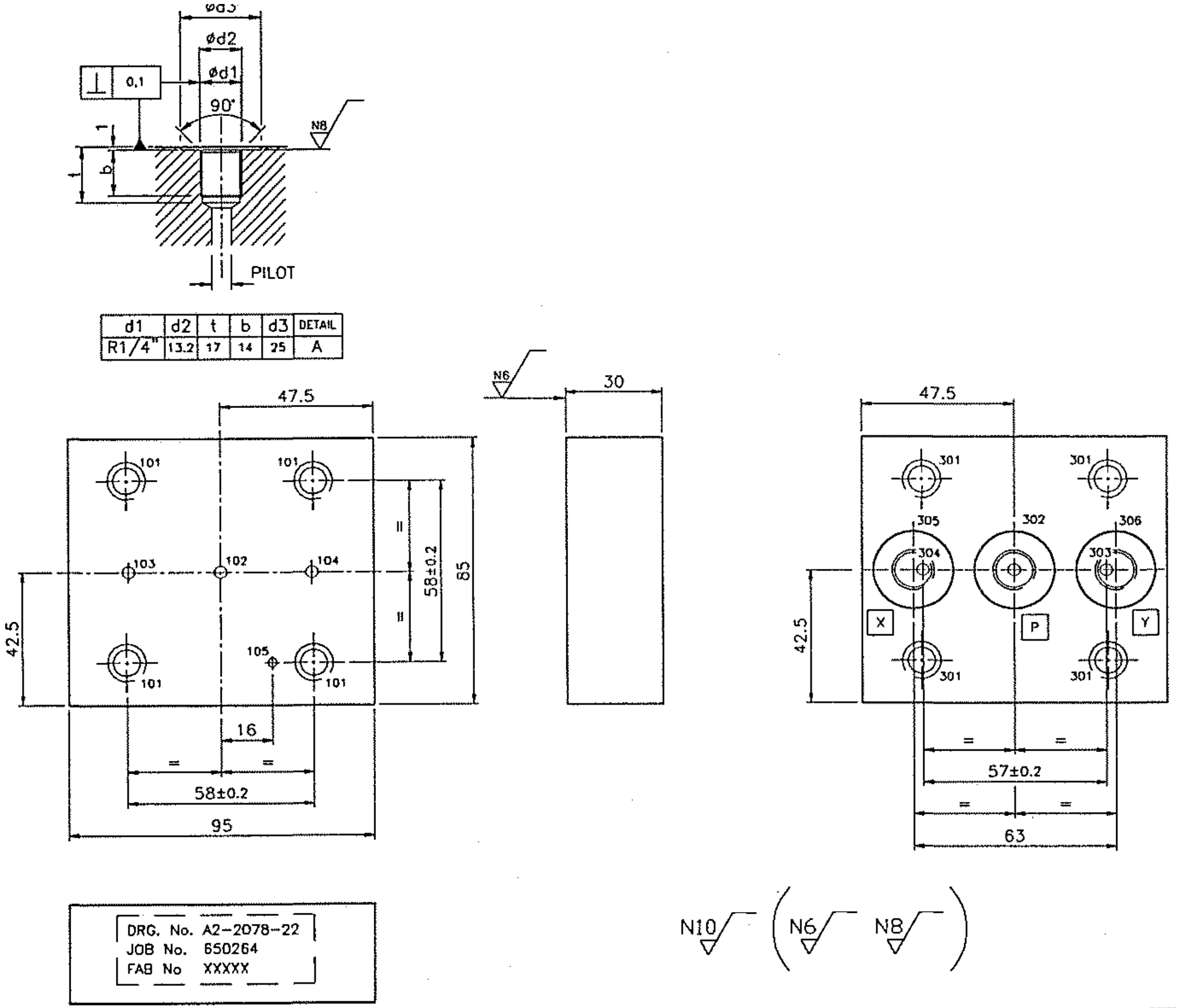
HYTEC NORTH (PTY)LTD

(ORIGIN:) A3–2078–231

DESCRIPTION
THREADED PLUG
FOR CSS–20–1

DRAWING IDENT. No
A320782300

(SUPERSEDED BY:)
(SUPERSEDES:)



NOTE :
1-REMOVE BURRS, SHAVINGS AND SHARP EDGES.
2-HOLE MARKED ☐ TO BE STAMPED 3mm BY HYTEC.
3-DRG. No., JOB No. & FABRICATION No.TO BE STAMPED AT POSITION INDICATED BY HYTEC. (AS PER DOCUMENT WI-70-03).
4-HOLE DEPTHS AS PER DOC. No. JHB-DO-STD-05.

OVERALL SIZE 95x85x30

HYTEC
1999 -03- 17
SPARTAN
DRAWING OFFICE

JOB No. 650264

CUSTOMER
PROJECT
REMARKS

SCALE 1:1	WEIGHT ± 1.65 Kg
MATERIAL EN8 FORGING	SHEET 2 OF 2

DESCRIPTION
ADAPTOR
(USED TO TEST SHOCK ABSORBER MANIFOLD COVER)

	DATE	NAME
DESIGN		
DRAWN	17-03-1999	ECD
CHECK	17-03-1999	
APP.	17-03-1999	

GENERAL TOLERANCES OF FORM & POSITION DIN 3141 RS

CAD SABS

HYTEC NORTH (PTY)LTD
(ORIGIN) A2-2078-202

DRAWING IDENT. No
A2 2078 2000

MATLAB Model Results A 5.1

The information in this annexure forms part of chapter 5 where model and experimental data are correlated. Since stable functioning of the MATLAB model was not obtained, this discussion is not included in the main text.

The MATLAB model developed uses lumped orifices and fluid volumes. Unfortunately very few stable solutions were found with the MATLAB model. As mentioned in paragraph 3.9, the MATLAB model used was simplified by removing the flow connection of the pilot circuit (WSE3 valve) from the main system flow. To test the validity of this assumption, one model with the flows incorporated was correlated with the standard model without the flows in figure A5.1. From the figure (note magnified scale) it is clear that the additional flow connection does bring the model closer to the AMESim trend, but that it does not alter the dynamics of interest materially. The different initial behaviour of the model could, however, affect the calculated 5% or 95% base delay value, depending on the overall flow through the valve.

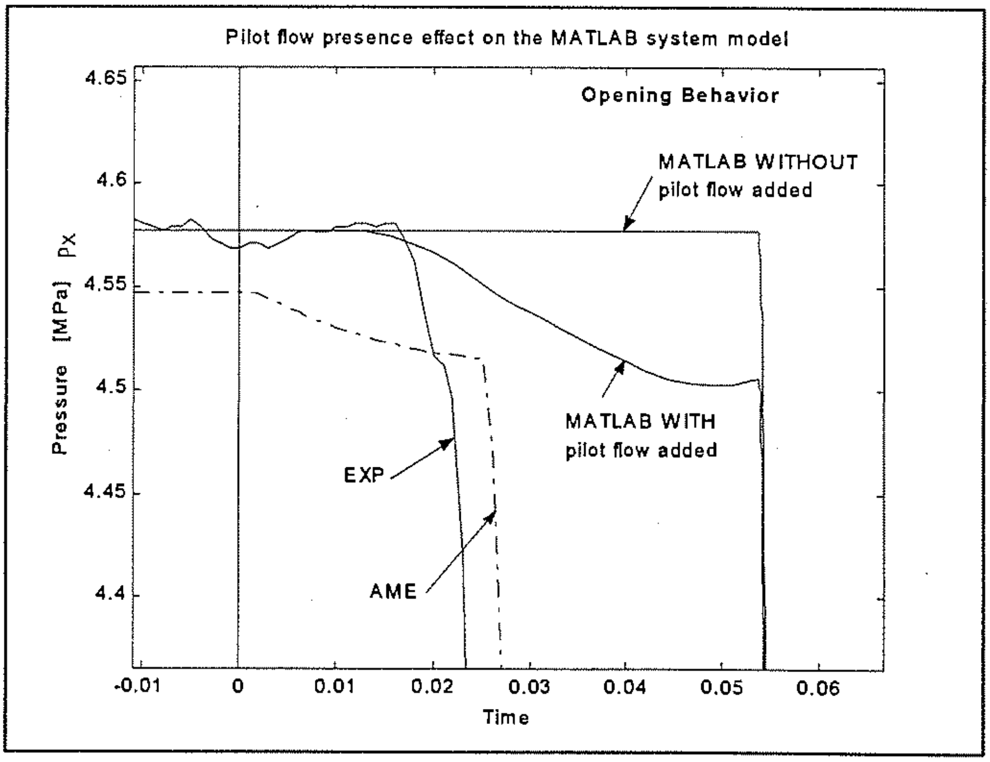


Figure A5.1 Experiment regarding pilot valve circuit flow addition in the MATLAB model.

Another assumption initially made in the MATLAB model is that the logic element poppet chamber is a static fluid volume (does not create a flow when its volume changes, Flowrate = poppet speed * poppet area). Upon investigation it was found that because of the poppet speed, the flow rate generated is not negligible. Adding the poppet chamber flow caused further instability in the MATLAB solver. This can be seen from figure 5.13. In this figure the integrator tolerance requirements were changed to test for convergence. The solutions generated did not converge and required many days to compute. In the few cases where a solution was found, the poppet velocity profile matched the AMESim velocity profile much better. This indicates that the initial assumption is not valid (relative to AMESim at least). Numerical experiments conducted included adding only a fraction of the poppet chamber flow to investigate the model sensitivity. This proved unsuccessful and stability was not reached (This was done using the 'Frac' term in equation 4.13).

It is not feasible to show all the versions of MATLAB models created. In general it is expected that for a tighter tolerance requirement on the solver a more stable (and accurate) solution should be obtained. However, a specific solution is only stable for a certain band of tolerance requirements. Some of the errors obtained are listed in general format:

- Warnings that the Jacobian matrix is badly conditioned or singular.
- The solution file generated is to large to handle. A Pentium II computer with 265Mb Ram ran out of memory (even with disk swap space available).
- The integration step size required by the solver is smaller than the machine precision. For one specific simulation run it was calculated that a 5 second run would require three years to compute at the ruling simulation speed.
- Completely random or trivial solutions found.

The MATLAB ODE suite (a set of DEQ solvers) contains several different integration algorithms. The ODE15s algorithm produced the best results. All the other algorithms were tested, but either took far more time to solve with many singularity warnings or did not find a solution at all.

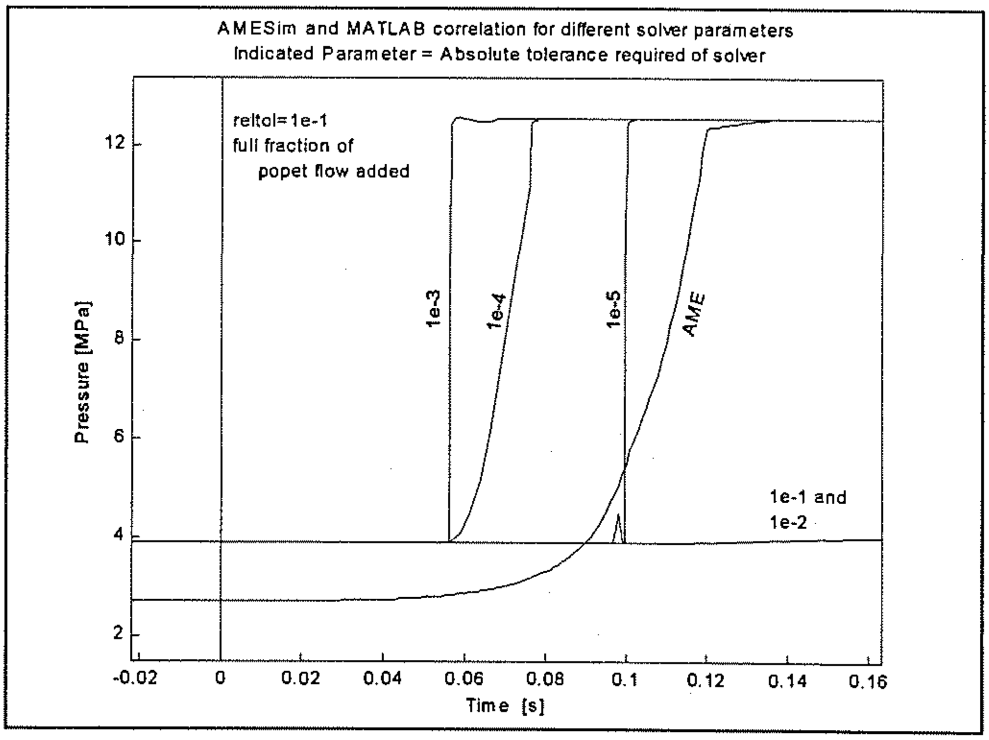


Figure A5.2 MATLAB solver instability for different tolerance requirements. The model has the full poppet chamber flow added.

Photographs

A 6

Photo 1	Two test bench pumps with oil reservoir
Photo 2	Detail of single test bench pump
Photo 3	Modacs data acquisition system and power supply
Photo 4	Linear damper with bypass valve system visible on lower side
Photo 5	Valve system with parallel damper mounted on test bench
Photo 6	Manifold CSS with pressure transducers and pilot valve fitted
Photo 7	Valve system mounted in test bench with drum to receive drain line oil (Final experimental pipe configuration not shown.)
Photo 8	VS1 flowmeter with CP108 check valve fitted in a mounting block. Pressure transducers are connected on each of the two CP 108 ports.

PHOTOGRAPHS

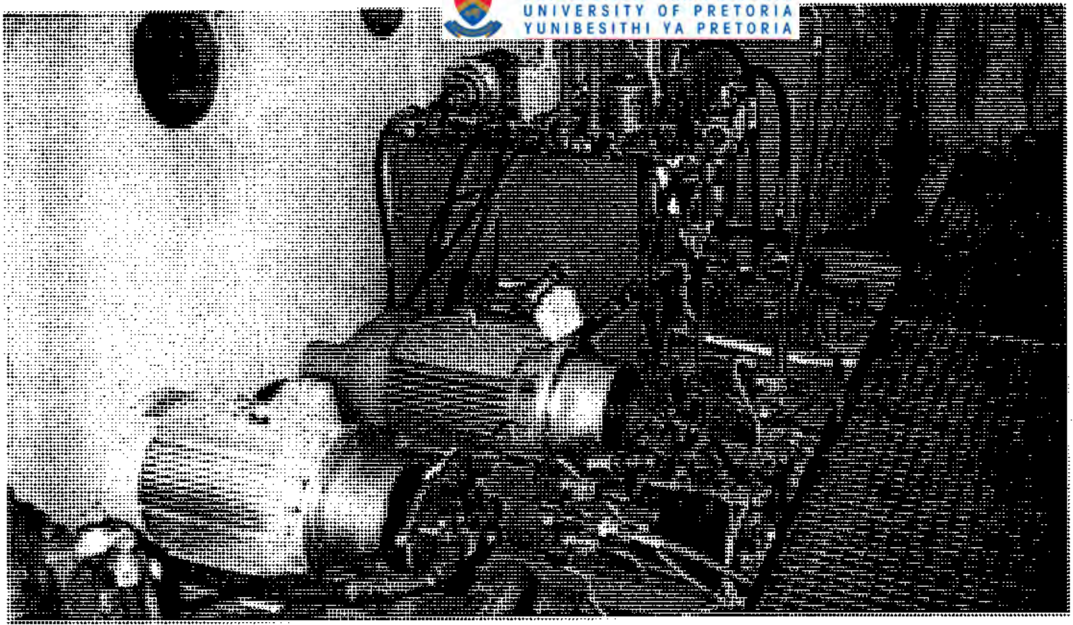


Photo 1 Two test bench pumps with oil reservoir

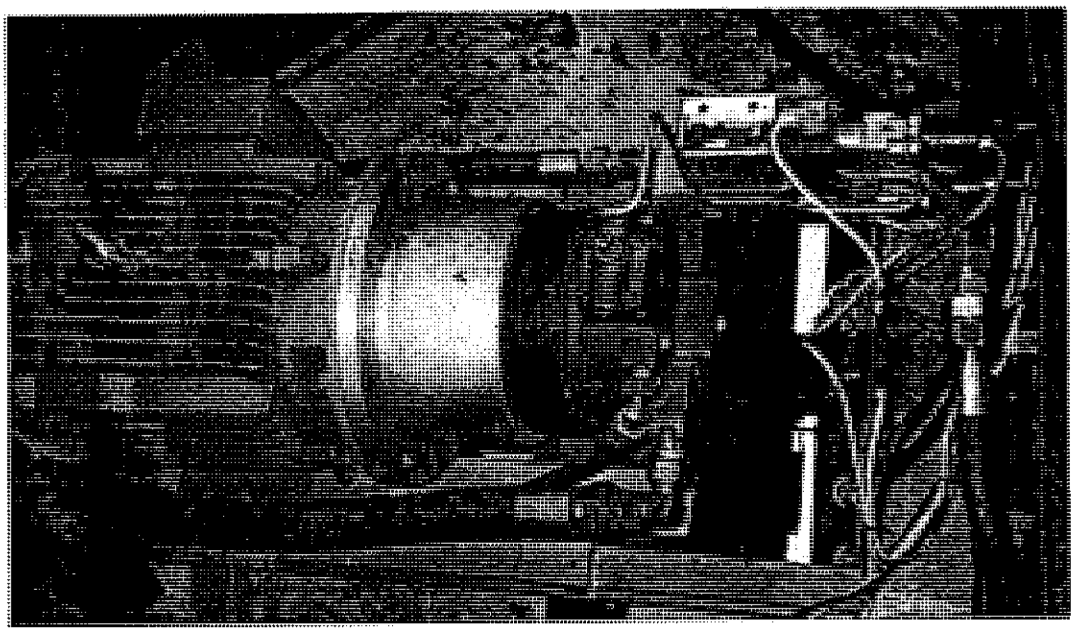


Photo 2 Detail of single test bench pump

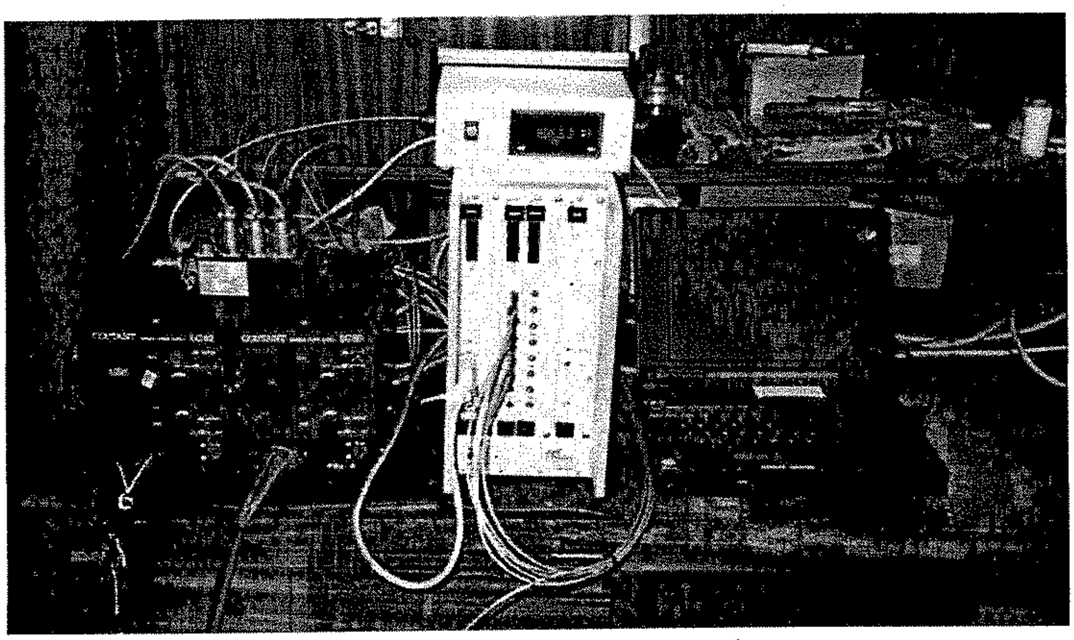


Photo 3 Madacs data acquisition system and power supply

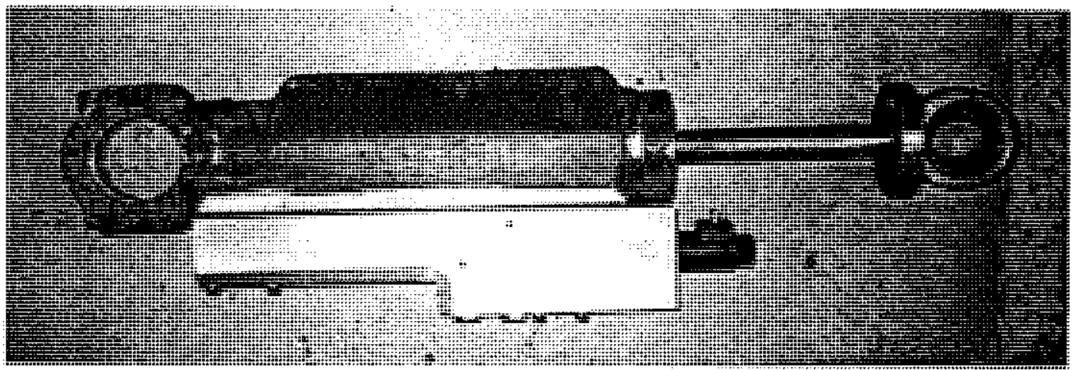


Photo 4 Linear damper with bypass valve system visible on lower side

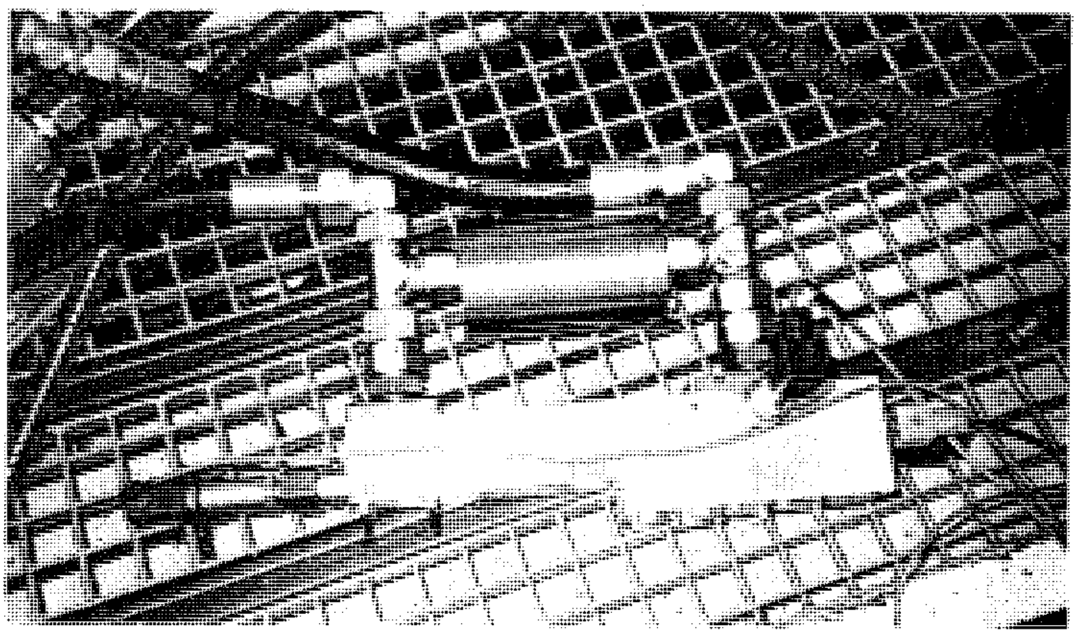


Photo 5 Valve system with parallel damper mounted on test bench

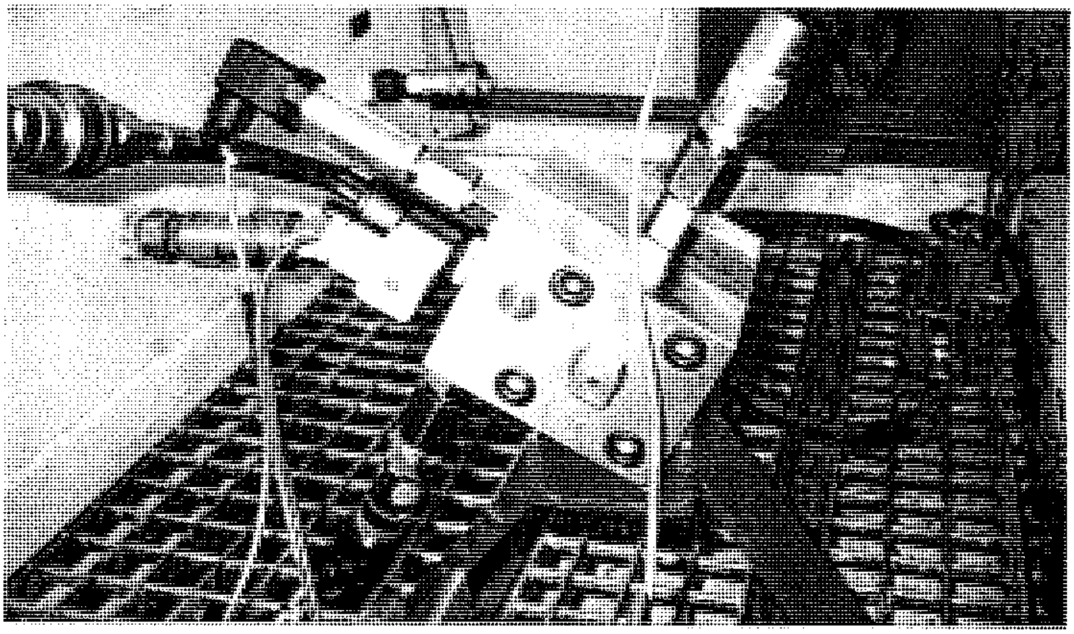


Photo 6 Manifold CSS with pressure transducers and pilot valve fitted

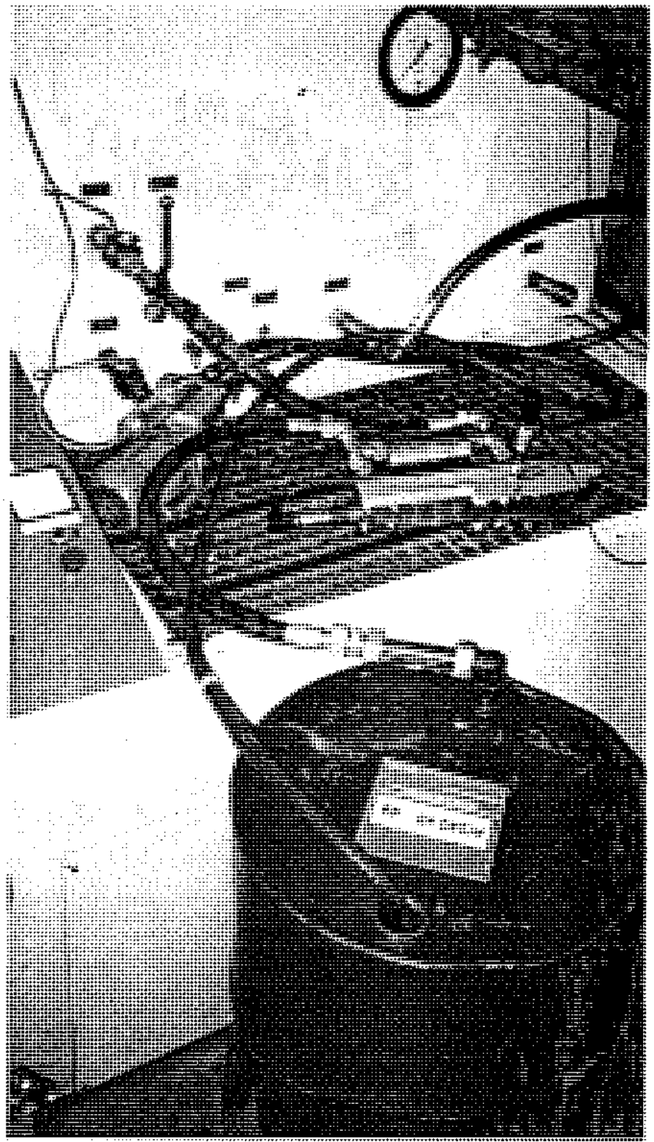


Photo 7 Valve system mounted in test bench with drum to receive drain line oil (Final experimental pipe configuration not shown).

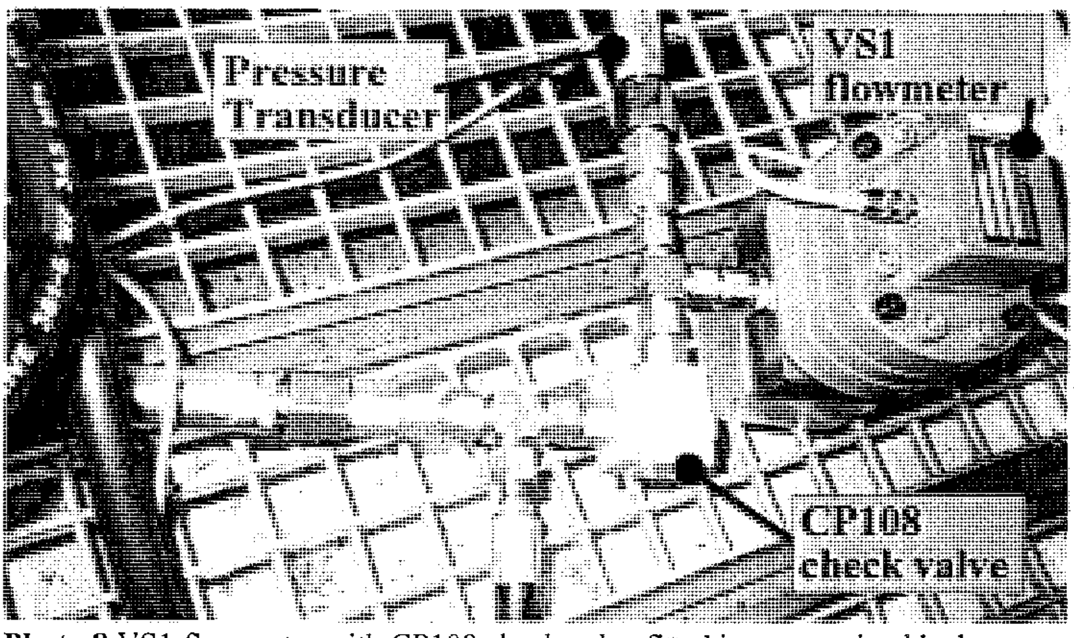


Photo 8 VS1 flowmeter with CP108 chech valve fitted in a mounting block. Pressure transducers are connected on each of the two CP 108 ports.