UiA University of Agder

Master

Pump controlled hydraulic cylinder with large inertia loads

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Abstract

This thesis is centered around the commissioning, testing, modeling and experimental validation of a pump-controlled hydraulic actuator capable of controlling large inertia loads. Prior to the thesis an experimental test bed had been constructed mechanically and hydraulically, and placed at the University. The primary focus of this thesis has been finalizing the experimental test bed in terms of building the electrical setup, placing instrumentation, developing software, tuning the electrical motors, followed by commissioning and testing of the experimental system. At the time of completing the thesis, the system has been completed, successfully commissioned and tested with position feedback-control. A numerical simulation model has been developed and validated against experimental data, with good agreement between the developed model and the experimental systems behavior. The real systems energy consumption has been measured and compared to that of a conventional servo valve controlled system, and shown to be significantly less while still capable of controlling large inertia loads with high accuracy. Using position feedback control the pump-controlled system achieved a settling time of 2.3 seconds and 0.18 mm steady state accuracy for the maximum effective load of 10 000 kg.

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Chapter 1

Introduction

1.1 Background and Motivation

Valve controlled hydraulic cylinders are extensively utilized in the industrial sector and offer several advantages compared to electromechanical cylinders, especially for control of large inertia loads. Advantages of valve controlled hydraulic cylinders include robustness, long service life and large force capability. The energy efficiency is however much lower than that of electromechanical cylinders, because of valve throttling in valve controlled hydraulic systems. This has motivated a new field within hydraulic actuation, the use of pump-controller cylinders [6].

Pump-controlled cylinders are directly controlled by varying the pump speed using a variable speed motor, and therefore differs from valve controlled hydraulic cylinders. Use of variable speed pumps for controlling hydraulic cylinders offers high level of power-efficiency by eliminating the fluid throttling from hydraulic control valves. Pump-controlled cylinders therefore manages to offer a high power-efficiency due to the absence of valves and fluid throttling, while keeping the advantages of traditional hydraulic actuation systems [6].

Pump-controlled single-rod cylinder cylinders results in different flows in and out of the cylinder chambers, this must be taken care of by the hydraulic circuit. Hydraulic circuits for handling this flow difference has been proposed by using either one, two or even multiple hydraulic pumps for each cylinder. As a part of a research project by the University of Agder and a local company an experimental test bed has been constructed and placed at the university. The best bed, shown in Figure 1.1, has been constructed to test single-pump actuation, dual-pump hydraulic actuation and a conventional valve-controlled circuit. [6][8].

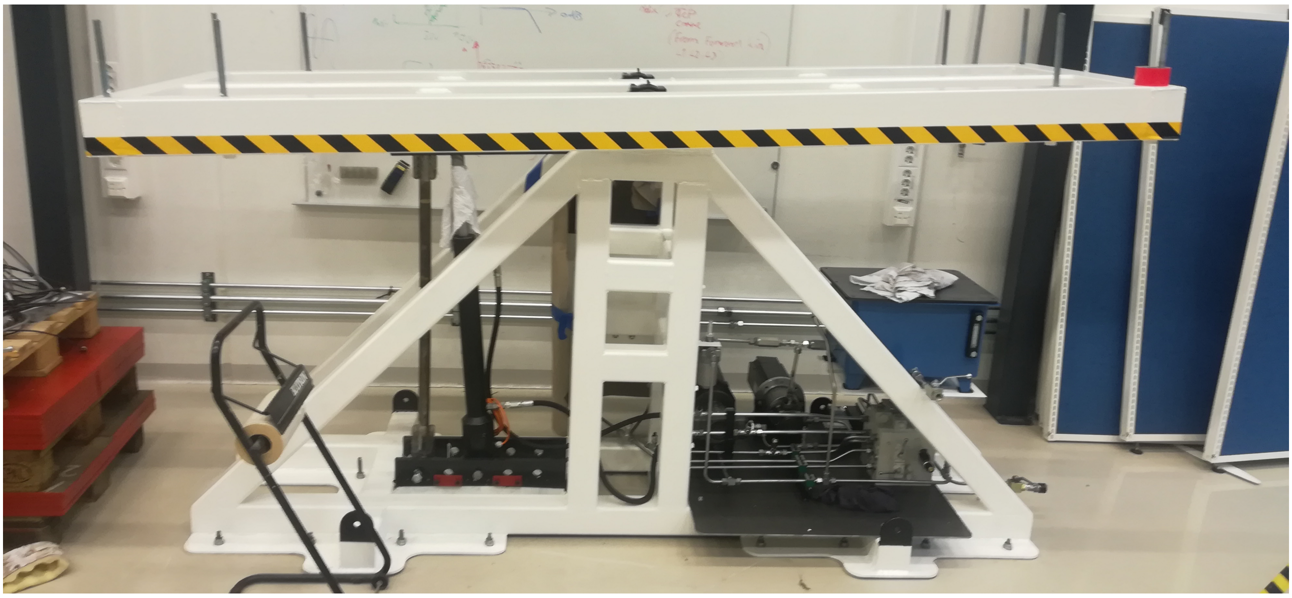


Figure 1.1: Experimental test bed

The dual-pump circuit utilizes a second pump to compensate for the different in and out flow of the cylinder. This is done by adding an additional pump as shown in Figure 1.2. The secondary pump compensates for the mismatching cylinder flow by supplying/subtracting the flow difference. The test bed has been constructed for testing a specific dual-pump circuit, where each pump has its own electrical motor. Although a single motor may be used for both pumps, using two pumps has the advantage of allowing the pressure of the cylinders to be controlled, in addition to its velocity or position [13].

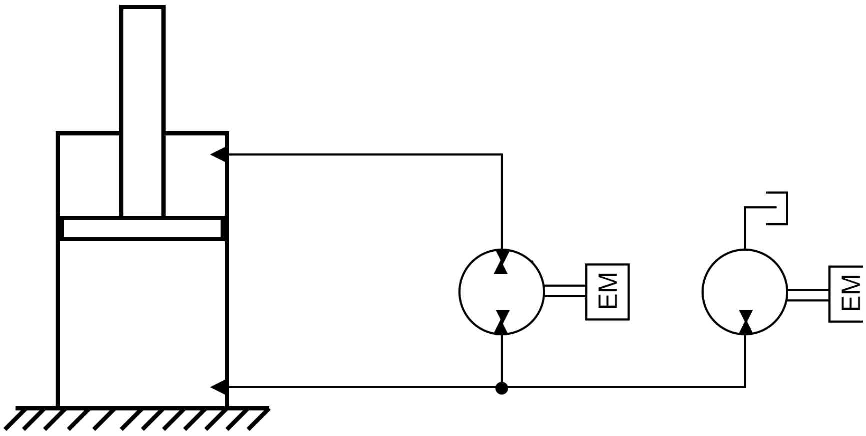


Figure 1.2: 2-pump system

1.2 Problem Statement

The primary objective of this thesis is to commission, test and document the behavior of the 2-pump circuit shown in Figure 1.2. Furthermore, the performance of the circuit is to be both tested and documented using position-feedback control of the cylinder. For the primary object the following requirements are given:

- Commission and test the functionality of the 2-pump circuit
- Develop a simulation model of the 2-pump circuit
- Implement position-feedback control of the cylinder
- Test and document the system behavior for both step- and sinusoidal signals
- Develop and deliver a software suitable for controlling the system
- Set up and deliver real time graphing and logging software of the test bed

Commission and test the functionality of the 2-pump circuit
The 2-pump circuit is to be commissioned and tested. The mechanical structure and hydraulics are done. A supplied PLC shall be set up and used for controlling the system.

Develop a simulation model of the 2-pump circuit
A simulation model of the 2-pump circuit shall be developed. Additionally, simplified linear modeling and analysis is to be done for the valve circuit and 1-pump circuit.

Implement position-feedback control of the cylinder
A position control algorithm is to be implemented for the system. Said control algorithm should optimize for response time, steady state accuracy and settling time.

Test and document the system behavior for both step- and sinusoidal signals
Using the implemented control algorithm the system behavior for step and sinusoidal are to be recorded and documented.

Develop and deliver a software suitable for controlling the system
A software for system control, data logging and graphing is to be developed and delivered to the client. The software should allow for both manual and position-feedback control of the actuator. The software should allow for easy and tuning of said control law.

Set up and deliver real time graphing and logging software of the test bed
Software is to be developed that allows for real time graphing and data logging of the test bed. The software must be simple to use and is to be delivered to the client.

1.3 Report outline

Experimental Setup presents the circuit configurations possible with the valve manifold and test bed.

System Commissioning covers the work done with the mechanical, hydraulic and electrical system.

Modeling introduces the system parameters for all models, the non-linear 2-pump model and the linear model of the 1-pump and servo valve circuit.

Analysis shows system stability analysis for the linear models developed in the modeling chapter.

Experiment Design shows the design of the implemented control algorithm and briefly discusses the PLC signal precision, HMI, data logging, real time graphing and emergency stops that has been implemented on the experimental test bed

Results presents the results obtained using the 2-pump circuit.

Discussion discusses the results and methods used.

Conclusion concludes the work presented in this thesis and provides recommendations for further work.

Chapter 2

Experimental Setup

This chapter briefly shows the three primary configurations that the experimental test setup shown in Figure 2.1 and 2.2. The 2-pump circuit is the primary circuit analyzed in this thesis with the two additional configurations covered.

Work done as part of the commissioning of the rig covered in Chapter 3.

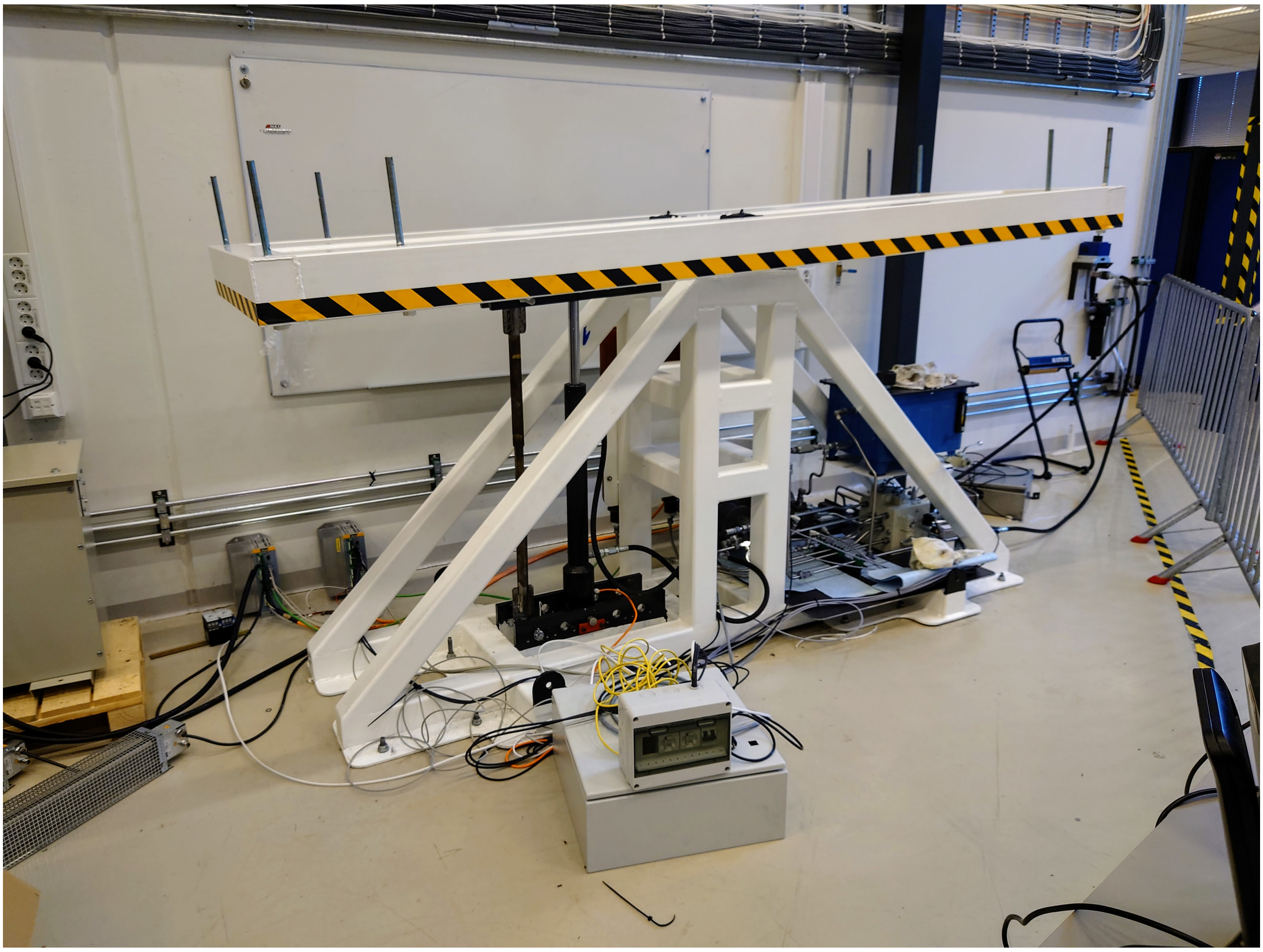


Figure 2.1: Test rig #1

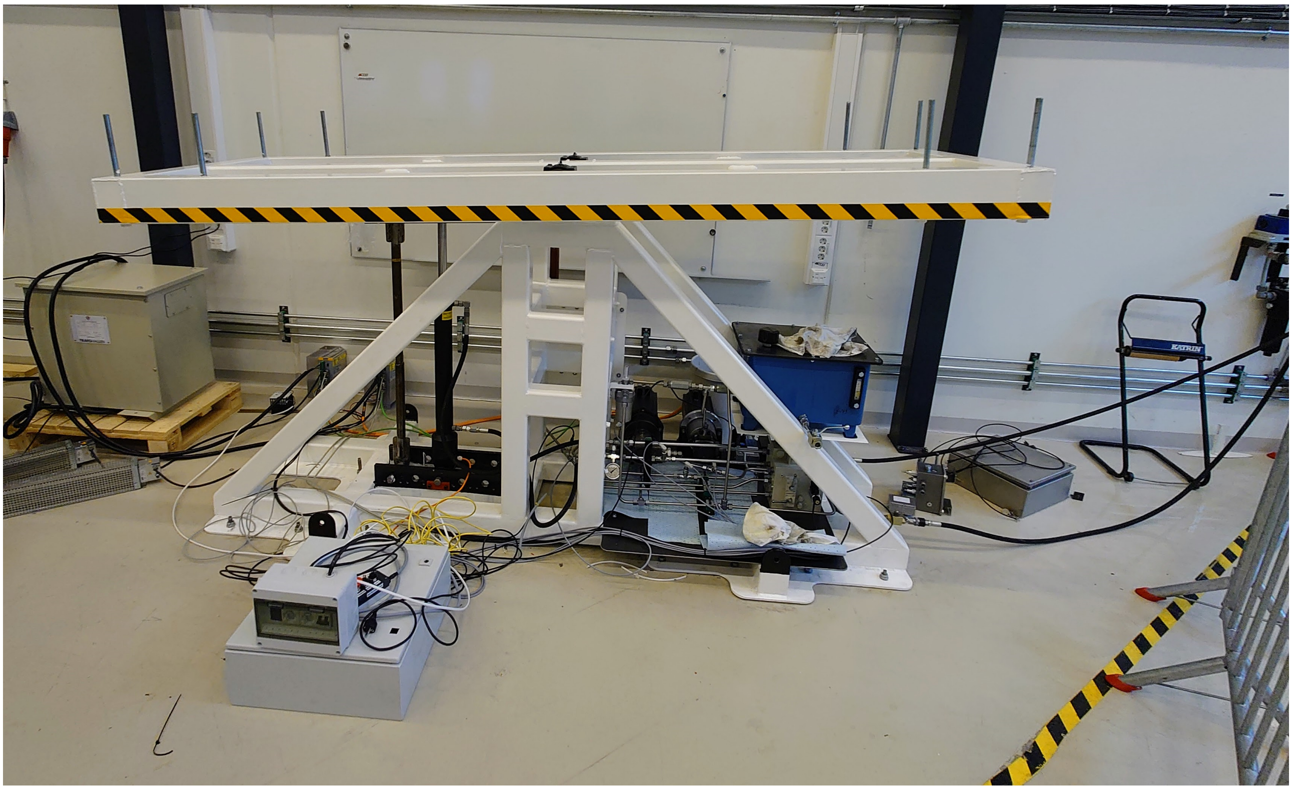


Figure 2.2: Test rig #2

2.1 Configuration A

In this configuration the cylinder is connected to a hydraulic pumping unit (HPU) trough a servo valve. The specific valve is a high performance MOOG D63 servo valve. Figure 2.3 shows a simplified schematic.

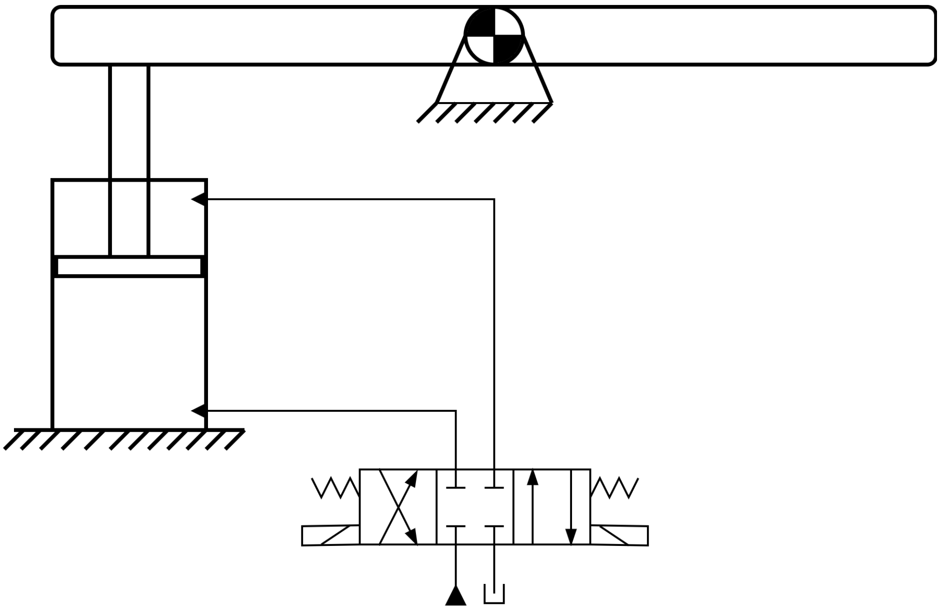


Figure 2.3: Platform with cylinder connected to HPU

2.2 Configuration B

In configuration B the hydraulic cylinder is connected to a single fixed displacement pump. The two accumulators allows the lowest pressure side to be held constant a either 1 bar or 30 bar. One direction valves connected to the accumulators for anti-cavitation protection. Simplified schematic in Figure 2.4

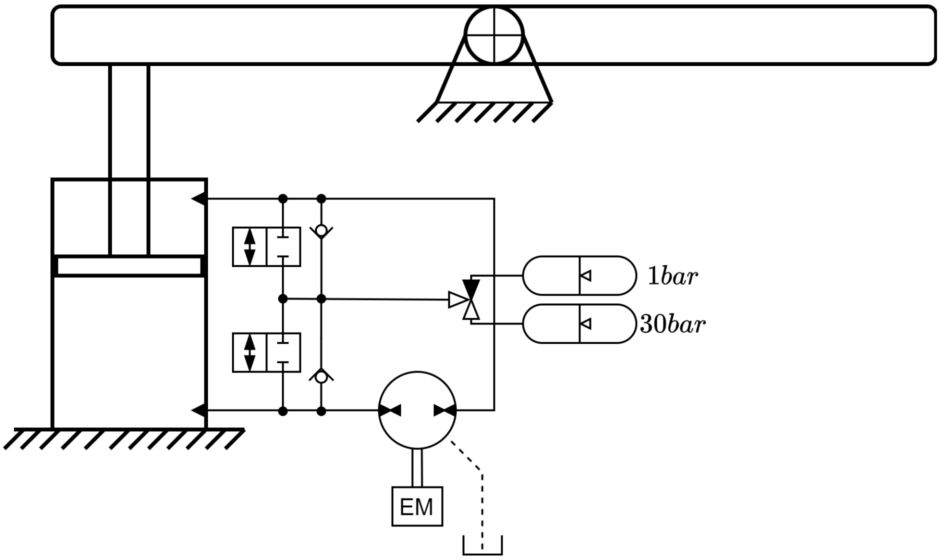


Figure 2.4: Platform and cylinder with a single pump

2.3 Configuration C

Configuration C expands on the previously discussed configuration with an additional fixed displacement pump. This secondary fixed displacement pump is utilized to add/subtract oil flow such that for the cylinder flow in equals flow out. Simplified schematic in Figure 2.5.

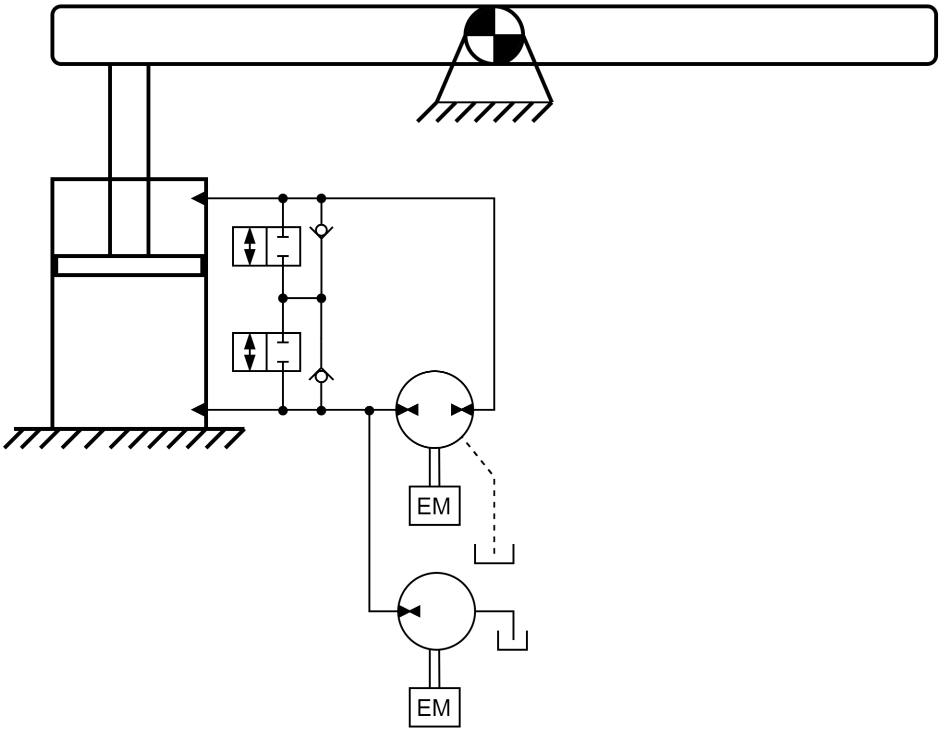


Figure 2.5: Platform and cylinder with 2-pump circuit

2.4 System Schematics

In this section the overview of the system is shown in Figure 2.6. The valve manifold, in Figure 2.4 [1], enables rapid switching between system configurations. The hydraulic system between valve 8.3 and 8.4 was not utilized in this thesis.

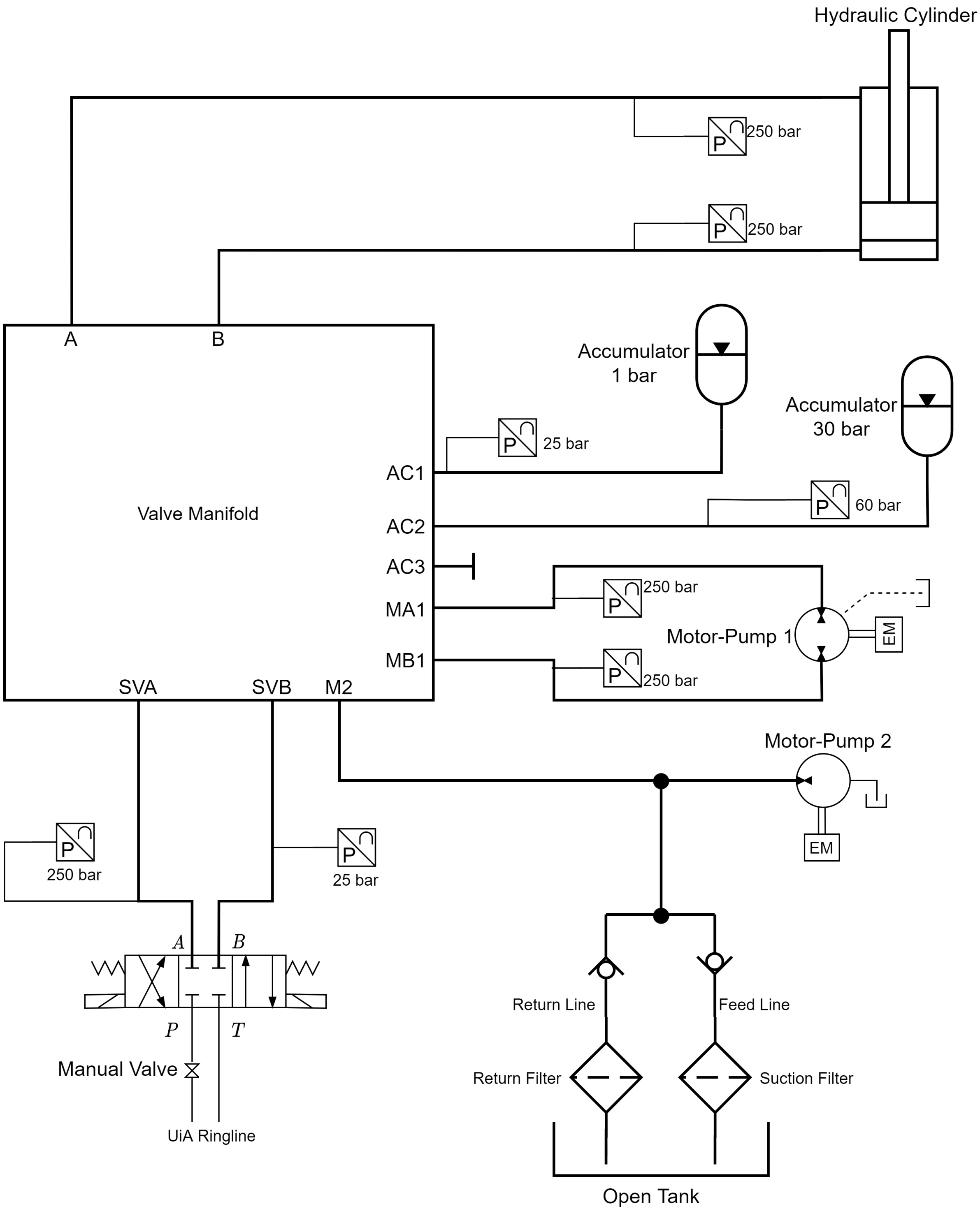
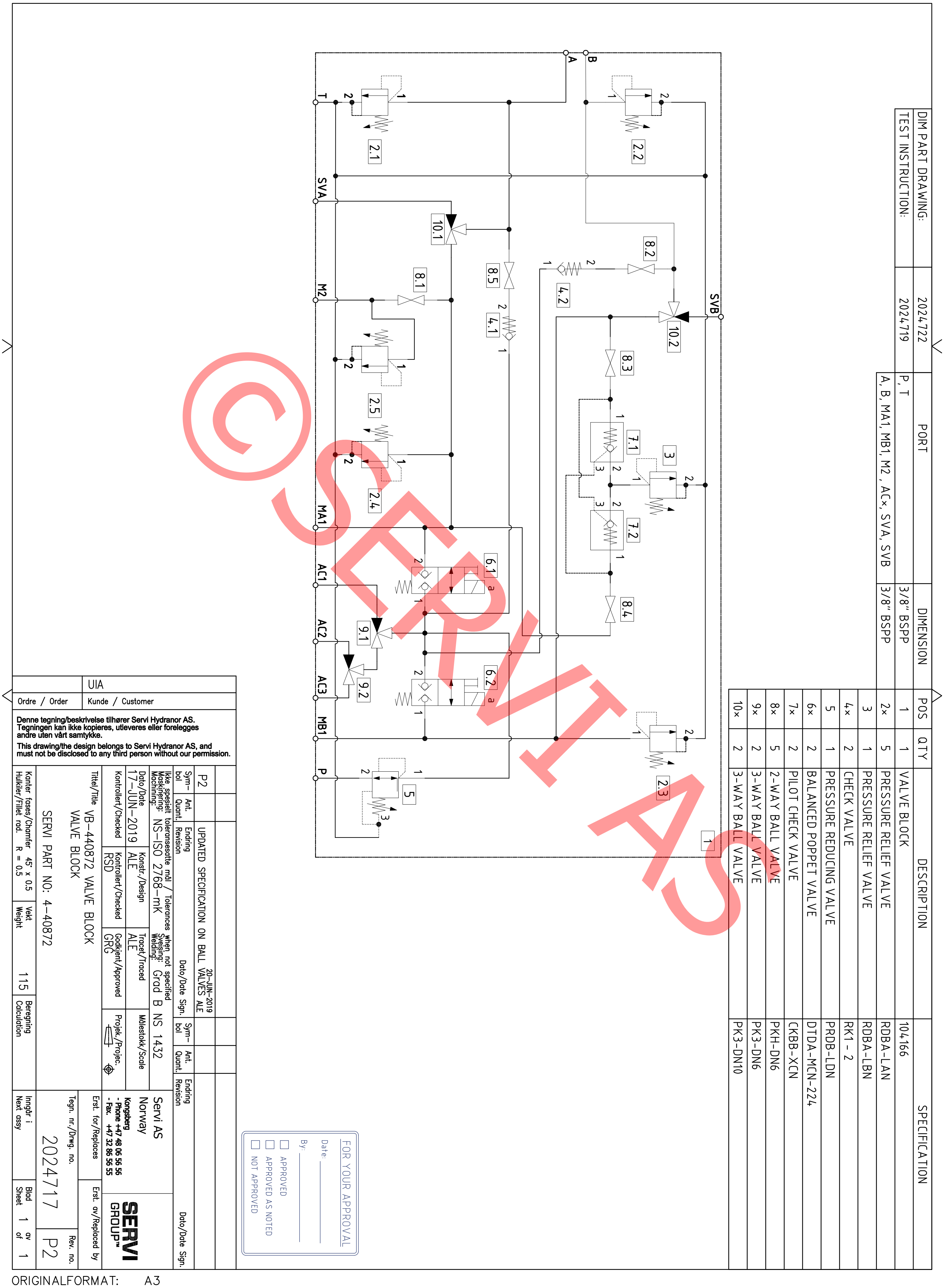


Figure 2.6: System Hydraulic Schematic

[1]Permission has been granted by Servi Hydranor AS to include the technical drawing in this thesis. Copyright notice on the drawing.



DIM PART DRAWING: 2024722
TEST INSTRUCTION: 2024719
PORT | DIMENSION
P, T | 3/8" BSPP
A, B, MA1, MB1, M2, ACx, SVA, SVB | 3/8" BSPP
POS | QTY | DESCRIPTION | SPECIFICATION
1 | 1 | VALVE BLOCK | 104166
2x | 5 | PRESSURE RELIEF VALVE | RDBA-LAN
3 | 1 | PRESSURE RELIEF VALVE | RDBA-LBN
4x | 2 | CHECK VALVE | RK1-2
5 | 1 | PRESSURE REDUCING VALVE | PRDB-LDN
6x | 2 | BALANCED POPPET VALVE | DTDA-MCN-224
7x | 2 | PILOT CHECK VALVE | CKBB-XCN
8x | 5 | 2-WAY BALL VALVE | PKH-DN6
9x | 2 | 3-WAY BALL VALVE | PK3-DN6
10x | 2 | 3-WAY BALL VALVE | PK3-DN10
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P2 UPDATED SPECIFICATION ON BALL VALVES 20-JUN-2019 ALE
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Welding:
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Kontrollert/Checked RSD
Godkjent/Approved GRG
Projek./Project.
Servi AS
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- Phone +47 48 06 56 56
- Fax +47 32 86 56 55
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Chapter 3

System Commissioning

This chapter covers the work with system commissioning. The platforms mechanical structure was constructed prior to this thesis and modifications was made to the structure.

3.1 Mechanical Work

3.1.1 Hydraulic Cylinder Mounting

Originally the hydraulic cylinder was only mounted by bolts trough either hole. This was deemed insufficient as neither bolt was secured against sliding. The two mounting bolts on Figure 3.2 was fitted with a axle holder as shown in 3.2.

The axle holders made per the DIN 15058 standard and are located diagonally opposite to one another.

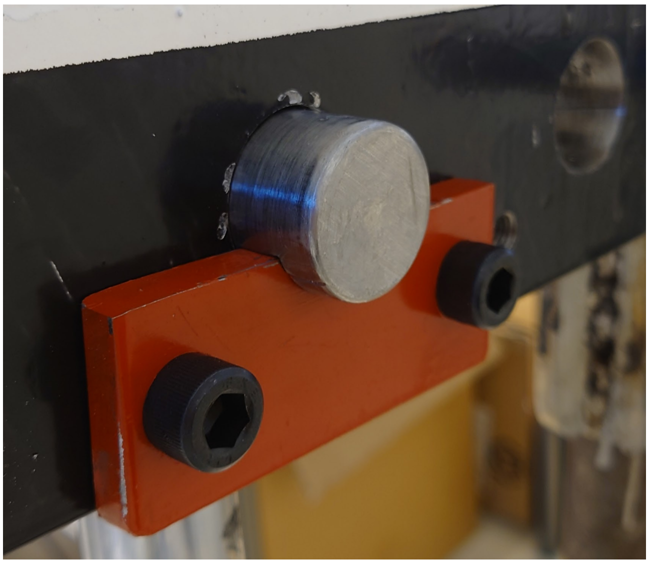


Figure 3.1: Axle holder

Figure 3.2: Cylinder bolts

3.1.2 Load Plates Modification

The load plates, used for increasing the system inertia, was ordered prior to this thesis. It was discovered that the threaded rods, marked on Figure 3.3, was mounted slight angled and it was not possible to place the load plates onto the rig. This was only discovered once the plates was to be moved onto the experimental setup, the timing meant that testing the system with inertia was delayed.

Every of the four holes on the 24 plates was widened, and it was possible to load the plates onto the test bed and perform system tests.

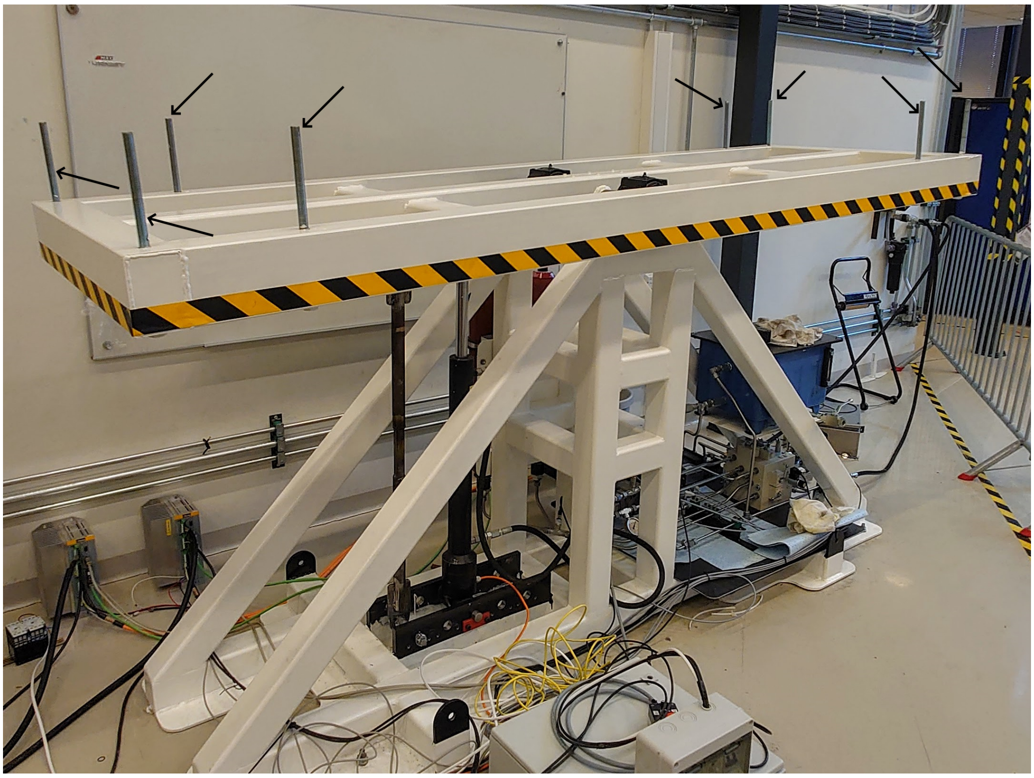


Figure 3.3: Plate rod mounts

3.2 Hydraulic Work

3.2.1 Oil Filter

The servo valve circuit from configuration A, Chapter 2, requires particles filtering of 10 μm with preferred filter size of 6 μm to improve the valves lifespan[1]. Filter size of 6 μm was selected to ensure longer lifespan. The chosen filter was sized for the HPU outputs, respectively 75 L/min and 210 bar.

The industrial HP320-1-A06AH-P01 filter was selected as it satisfies the flow, pressure and filter requirements. The filter was installed in a suitable filter housing with out bypass. Filters datasheet appended in Appendix C.7.

3.2.2 Tank Breathing Filter

The open tank was closed to prevent particles in the air entering the system and contaminating the oil. A breathing filter was installed to eliminate pressure deviation from atmospheric pressure. The particle filter demand was set to 6 μm to match the particle filter for the oil from the HPU.

The maximum flow out of tank is when the secondary pump, which pulls directly from tank, operates on its theoretical maximum. The required air flow is determined by the dust concentration in the air, which are listed in filters datasheet. The dust concentration where the test rig is located is deemed to average.

From the chosen suppliers datasheet it is found that average dust concentration gives a factor of 5 and the maximum theoretical air flow is the theoretical oil suction from pump multiplied by 5. The filter then was sized for a flow requirement of 650 L/min, with the desired mounting method to be on the tank cover as for easy installation.

A Hydac tank breather filter, *BF P 3 G 10 W 1.0*, was selected as it meets the air flow and installation requirement. Datasheet in Appendix C.8.

3.2.3 Correcting pump connection

Initially it was discovered that the pump was connected over itself rather then between the cylinder chambers. This was corrected and every external hydraulic connection was confirmed to be as designed.

[1]From the valves datasheet, appended in Appendix C.1

3.2.4 1-pump Commissioning Problem

It was discovered that the valve that was intended to refill the two accumulators present did not work as intended. The pressure reducing valve was meant to reduce the incoming pressure to fill the two accumulators. Under attempted use of this functionality it was discovered that the valve dumped excess oil to the internal tank on the test rig, which is not dimensioned to handle the incoming extra oil.

This issue could not be fixed on location and required internal manifold changes which are outside the scope of this thesis.

3.2.5 Servo Valve Commissioning Problem

The servo valve circuit is connected to the hydraulic cylinder trough the valve manifold block. During testing it was discovered that the expected valve leakage characteristic, i.e. roughly half of the supply pressure on each cylinder side was not present. Due to issues with the oil leakage path only a tenth of the supply pressure was observed on either side of the cylinder. Additionally oil leaked over valve 10.1 and 10.2 (the vales used for switching between circuit types) to the tank trough pump drain. Both of these issues meant that the desired servo valve behavior could not be obtained and correcting the fix requires to the internal manifold, and outside the scope of this thesis.

3.2.6 Updated Hydraulic Schematic

With the changes to tank the original hydraulic schematic in Figure 2.6, under Section 2.4. Updated schematic follows below, in Figure 3.4.

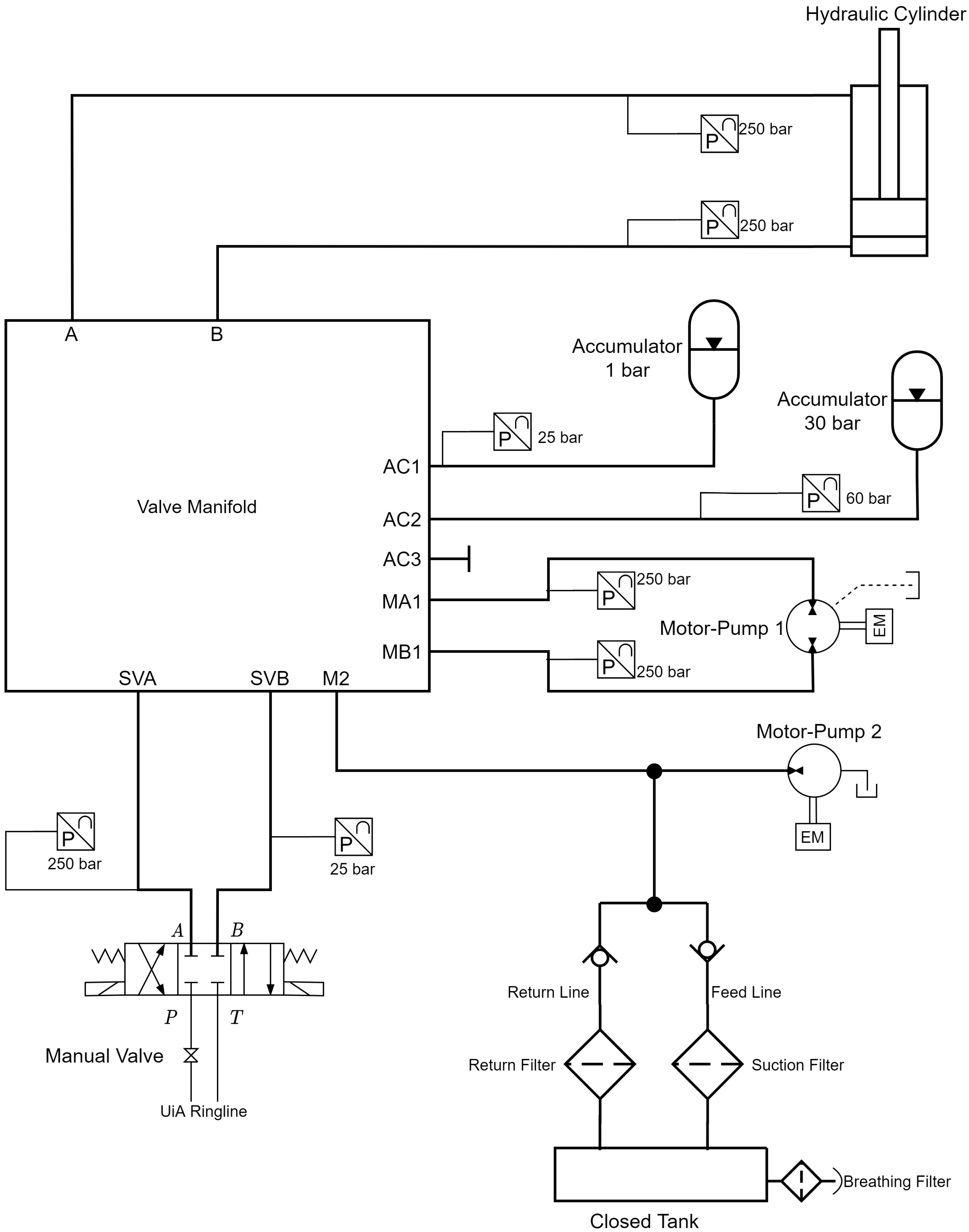


Figure 3.4: Updated System Schematic

3.2.7 System Flushing and Delays

In order to comply with the servo valve cleanliness the system was set to be flushed for any dirt by an external company. Firstly the company required a system inspection prior to the flushing, however due to the regulations surrounding covid this inspection was delayed several times. After some time the inspection was done by the company and a price was given. The flushing-cost was too expensive for this thesis.

This meant that the flushing had to be complemented without the external company and only after considerable waiting and delays.

3.3 Electrical Work

Each subsection contains layout for the specific part discussed, with the entire layout covered in Subsection 3.3.5.

3.3.1 Programmable Logic Controller (PLC)

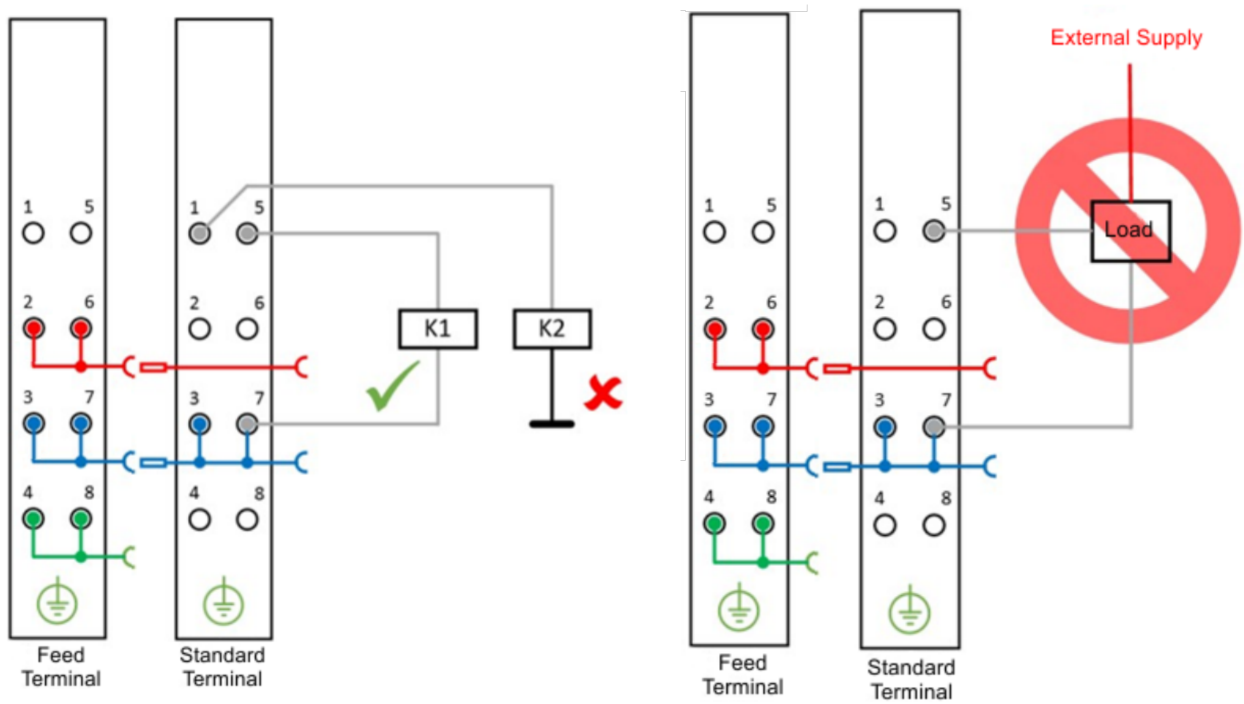
From the client it was requested implementation of a beckhoff PLC for system control. The PLC and necessary I/O cards was supplied by the client and are listed in table 3.1.

Name	Description
CX5140	PLC CPU
EL1859	8 channel digital 24V DC input/output
EL3064	4 channel 0. . . 10V single ended analog input
EL3002	2 channel -10. . . 10V single ended analog input
EL3102	2 channel -10. . . 10V differential analog input
EL3124	4 channel 4. . . 20mA differential analog input
EL3154	4 channel 4. . . 20mA single ended analog input
EL4132	2 channel -10. . . 10V analog output
EL4122	2 channel 4. . . 20mA analog output

Table 3.1: Supplied components

Correct Load Connection

All electrical connections adhere to the "correct load connections" defined by Beckhoff, every load connected to the PLC also required their return line connected to the PLC, as shown in Figure 3.5a. Additionally externally powered loads did not have their return line connected to the PLC, as illustrated in 3.5b.



(a) Correct and incorrect load

(b) Incorrect example

Figure 3.5: Examples of correct and incorrect connection [10]

3.3.2 Servo Drives

Two identical servo drives was used to power and control the motors. Each servo drive was installed with an on-off switch and supplied with 24 V DC. Three switches was installed to act as multiple levels of safety stops, the three different switches are all normally closed with their behavior being A) Opening the contact so the mechanical motor brakes turns on and hinders motor movement B) Opening the contact and activating the servo drives "internal power stage output interrupt" C) Opening the two contactors and interrupting the 230 V 3-p supply voltage to the drive.

The electrical layout for the servo drives are shown in Figure 3.6. Note that for simplicity only a single contactor is shown, the contactor for drive #2 is similarly connected and linked to the same EM-button. Also note that the brake shown on the figure refers to the mechanical motor brake and is drawn only to illustrate the electrical layout, in reality the mechanical motor brake is controller by the respective servo drive. The PLC is thus used to toggle the breaks by logic signal to the drives and may be interrupted by mechanical switches.

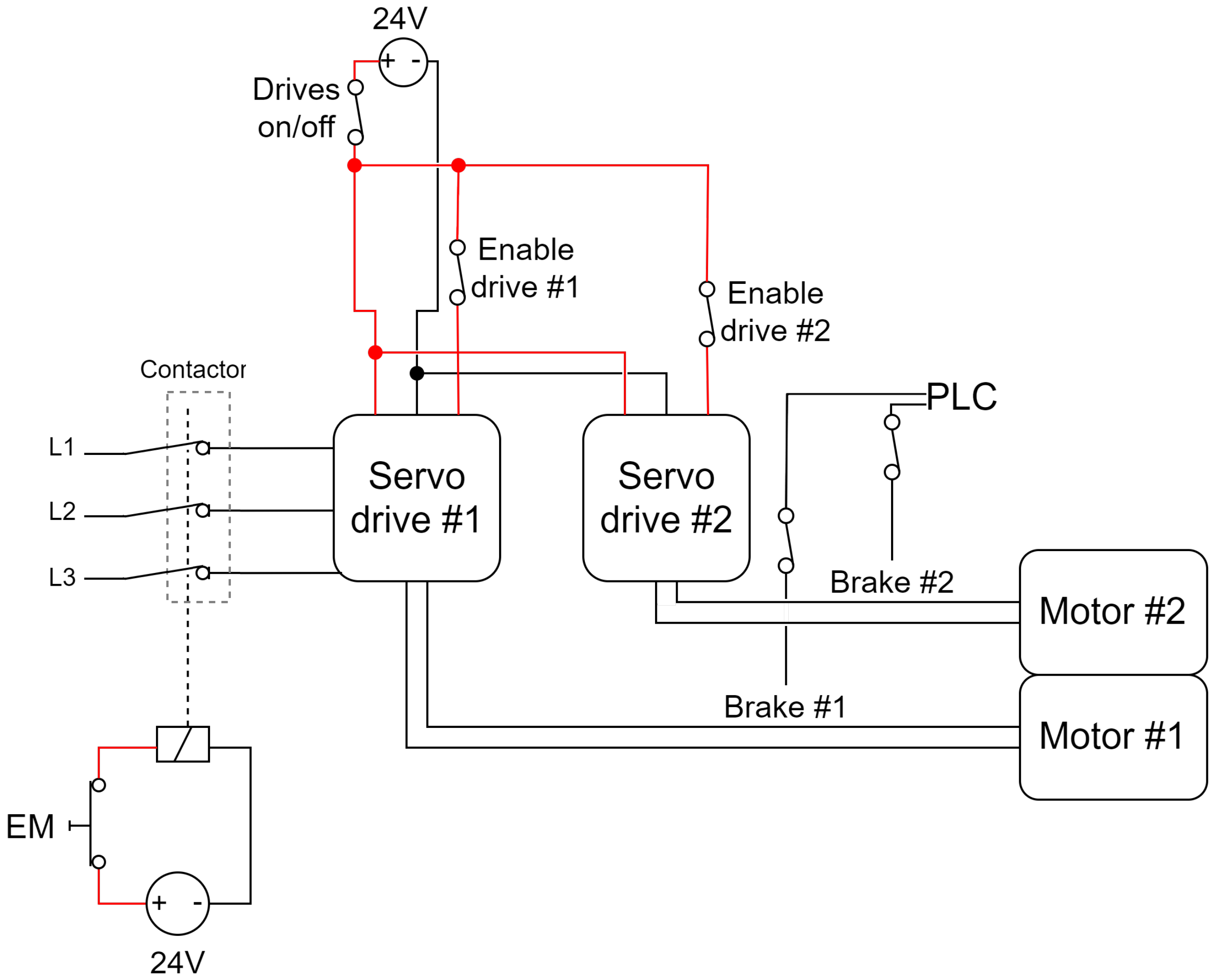


Figure 3.6: Servo drive and connected electronics

3.3.3 Transformer for Servo Drivers

After the onset of the thesis, it was discovered that the the servo drives available at the test rig could not be powered at the University laboratory due to lack of 230 V 3-phase supply.

The client was unable to provide a permanent solution due to budget reasons, therefore it was decided to rent a 400 V / 230 V transformer with 30 kVA power supply such that both motors could be supplied. Finding a supplier and getting the unit shipped to the university cause significant delay. Due to budget reasons, the transformer could only be rented for April and May, which limited the time available for commissioning and experimental testing.

3.3.4 Power Supply Unit (PSU)

This part briefly covers the selection of the PSU. Prior to selection the systems required current consumption, the voltage requirement for all system components being 24 V DC (otherwise the components utilizes AC or internal converters).

Each component was evaluated with regards to their maximum current consumption, listed in Table 3.2. The servo drives and servo valve never operates simultaneous and thus the maximum consumed current is found to be $\sim$ 8.3 A. A 1.2 safety factor was implemented to account for efficiency losses and thus implemented PSU should be capable of delivering 10A.

Component	Max possible consumption
PLC	1A
Misc PLC cards & equipment (Conservative estimate)	2A
6x pressure sensors	6x 20mA
Servo valve	1.2A
2x Servo drive	2x 2.6A

Table 3.2: Current consumption

The PSU must also be approved to use for industrial control equipment, and have protection against short-circuit, overload, overvoltage and overheat.

A 24V Mean Well power supply was chosen to power the PLC and equipment, PSUs datasheet appended in Appendix C.2. The Mean Well PSU is certified for industrial control equipment and features the necessary protections to ensure that the system is sufficiently protected. The PSU can supply up to 10A continuously during normal operation.

3.3.5 Layout & Electrical Enclosure

This subsection shows layout for all components together. Both PLC and PSU was mounted in a electrical enclosure and a layout was created to plan the installation. The layout in Figure 3.7 was created based on requirements to component spacing and fuse requirement listed in each components installation requirement. A point was made to locate analog signals, especially current signals, as far as possible from the PSU to not introduce noise on signals.

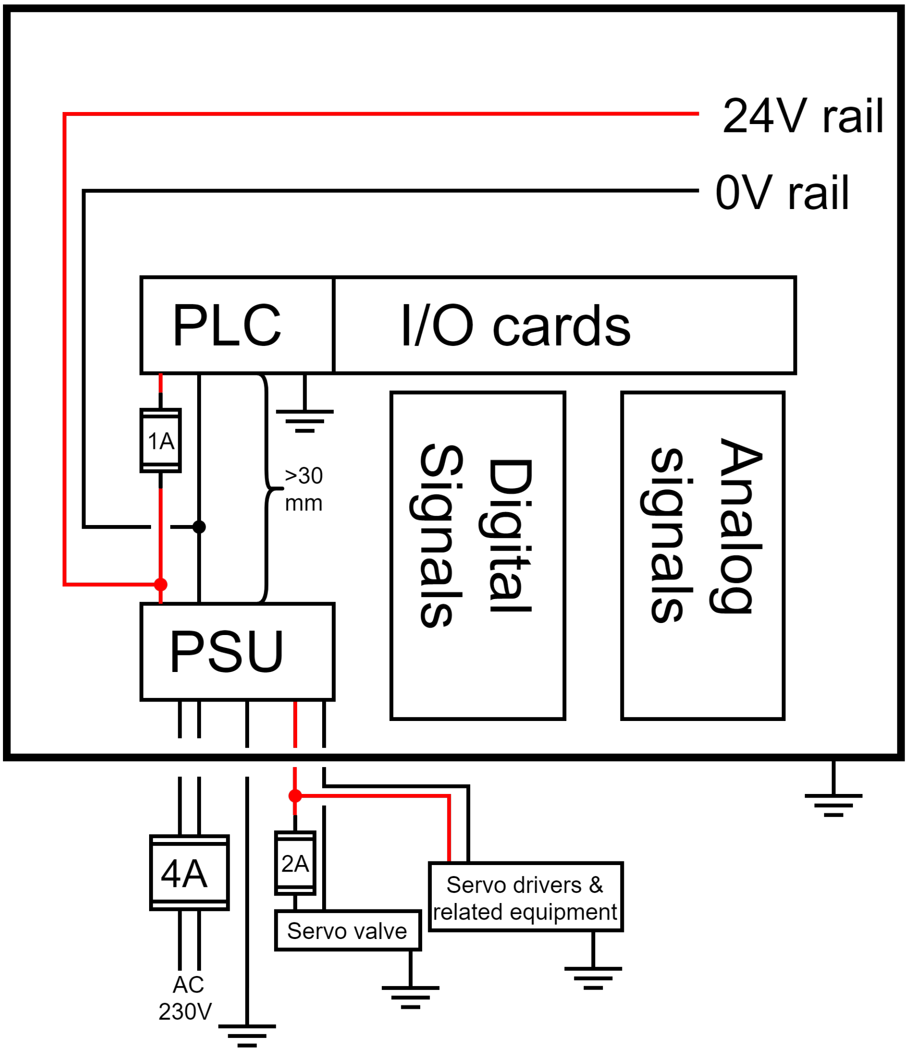


Figure 3.7: Electrical layout

Chapter 4

Modelling

4.1 System Parameters

This section covers system parameters. Derivation of parameters shown where relevant.

4.1.1 Servo Valve Flow

The valve on the rig has a rated flow of 40 L/min at 35 bar pressure drop across a metering and the discharge coefficient was found by the orifice equation, Equation 4.1. The orifice equation was rearranged and $C_d \cdot A_{d,max}$ was found to be $7.3463 \cdot 10^{-6} m^2$, by Equation 4.2. The oil density of 850 kg/m^3 is assumed.

$$Q = C_d \cdot A_d \cdot \sqrt{\frac{2}{\rho} \cdot \Delta P} \tag{4.1}$$

$$\begin{aligned} C_d \cdot A_{d,max} = K_d &= \frac{Q_{rated}}{\sqrt{\frac{2}{\rho} \cdot \Delta P_{rated}}} \\ &= \frac{40 L/min}{\sqrt{\frac{2}{850 kg/m^3} \cdot 35 bar}} = \frac{40}{\sqrt{\frac{2}{850} \cdot 35}} \cdot \frac{\sqrt{10^{-11}}}{60} m^2 = 7.3463 \cdot 10^{-6} m^2 \end{aligned} \tag{4.2}$$

The calculated valve coefficient is valid for a fully open metering, the flow characteristic curve lists a linear relation between flow and valve opening. This linear relation is used to add a valve opening variable, $u \in [-1, 1]$. The resulting equation, Equation 4.3, can be used to represent flow trough a valve opening for a given valve opening, u, at a given pressure differential ΔP. Equation 4.3 returns flow in m^3/s when inserting pressure in Pa, the valve opening is dimensionless.

$$Q = 7.3463 \cdot 10^{-6} \cdot u \cdot \sqrt{\frac{2}{\rho} \cdot \Delta P} = 3.5635 \cdot 10^{-7} \cdot u \cdot \sqrt{\Delta P} \tag{4.3}$$

4.1.2 Cylinder

The cylinders bore diameter is 63 mm, the rod diameter is 36 mm with a stroke of 500 mm. From the design specification of the cylinder, appended in Appendix C.3. Note that although the appended drawing is preliminary the diameters and stroke length is correct.

4.1.3 Mass Plates

Each plate weighs 58.27 kg, extracted from the CAD model with correct material properties.

4.1.4 Relief Valves

The systems relief valve all feature the same 2 ms typical response time with 45 L/min flow capacity. All valves are factory new.

4.1.5 Accumulators

Two accumulators exists in the system, 1 bar and 30 bar, each with $5L$ capacity.

4.1.6 Line Volume

Table 4.1 lists live volume between the parts, measured on the real system.

Description	Line Volume
Servo valve → Cylinder	$1.2723\ 10^{-4}\ m^3$
Main pump → Cylinder	$1.5904\ 10^{-4}\ m^3$
Secondary pump → Main pump	$1.2723\ 10^{-5}\ m^3$

Table 4.1: Volume Parameters

4.1.7 Main Pump Parameters

The main pump is a fixed displacement with with two directions of flow and two pressure sides. Table 4.2 lists key parameters for the *A10FZG006/10W-VSC02N00* pump. All parameters in the appended datasheet, in Appendix C.4. Pump efficiency is not listed in the datasheet, assumptions made in pump simulation part.

Symbol	Description	Value
p_{nom}	Nominal operating pressure	315 bar
V_m	Volumetric displacement	6 cm^3
n_{nom}	Nominal rotational speed	3600 rpm

Table 4.2: Main pump parameters

4.1.8 Secondary Pump Parameters

The secondary pump is a fixed displacement pump with one direction of flow and one pressure and suction side. Table 4.3 lists key parameters for the *IPVP 3-3,5-101* pump. Datasheet appended in Appendix C.5.

Symbol	Description	Value
p_{nom}	Nominal operating pressure	330 bar
p_{input}	Input operating pressure	$0.8 \ldots 3$ bar
V_m	Volumetric displacement	3.6 cm^3
n_{max}	Maximum rotational speed	3600 min^{-1}

Table 4.3: Secondary pump parameters

4.1.9 Motor Parameters

Both pumps use the same Parker motor, a low-inertia high dynamic brushless servo motor. The specific motor parameters for the *SMHA142301551921642* listed in Table 4.4. SMH - series datasheet appended in Appendix C.6.

Symbol	Description	Value
T_{stall}	Stall torque	15 Nm
T_{nom}	Nominal torque	12.5 Nm
n_{nom}	Nominal speed	3000 min^{-1}
T_{peak}	Peak torque	47 Nm

Table 4.4: Motor parameters

4.2 Mechanical Simplification

The entire mechanical platform with its hydraulic cylinder can be represented as a single mass on linear cylinder, illustrated in 4.1. This enabled the simplification of system dynamics and less computation with out affecting the system dynamics [3]. The simplified system is represented by 4.4, with the parameters as m_{eff} and F_{ext} being discussed below.

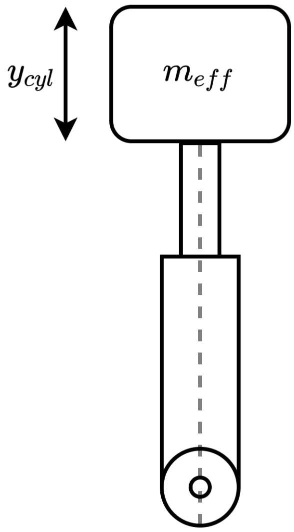


Figure 4.1: Simplified System

With the current simplification the mass that the cylinder experiences is denoted as m_{eff}. Similarly all external forces such as gravity and other are denoted as F_{ext}, the system friction is denoted as F_{fric}.

$$m_{eff} \cdot \ddot{y}_{cyl} = F_{cyl} - F_{ext} - F_{fric} \tag{4.4}$$

4.2.1 Effective Mass

Two methods will used to estimate the effective mass for the cylinder. The energy approach and by utilizing the "Simscape Multibody" simulink library [1].

Energy Approach

In this approach the effective mass is found by utilizing Equation 4.5 [3]. The kinetic energy for the platform, Equation 4.6, is converted from $\omega_{platform}$ to $\dot{y}$ by Equation 4.7. The conversion utilizes that the platform and cylinder head will have equal absolute velocity in point A on Figure 4.2. Note that both angles and distances on aforementioned figure are exaggerated for clarity and does not represent the real system.

[1]Simulink is the simulation and model based design part of Matlab.

$$m_{eff} = \frac{2 \cdot E_{kin}}{\dot{y}_{cyl}} \tag{4.5}$$

$$E_{kin} = \frac{1}{2} \cdot I_{eff} \cdot \dot{\theta}^2 \tag{4.6}$$

$$\dot{y}_{cyl} = r \cdot \dot{\theta} \tag{4.7}$$

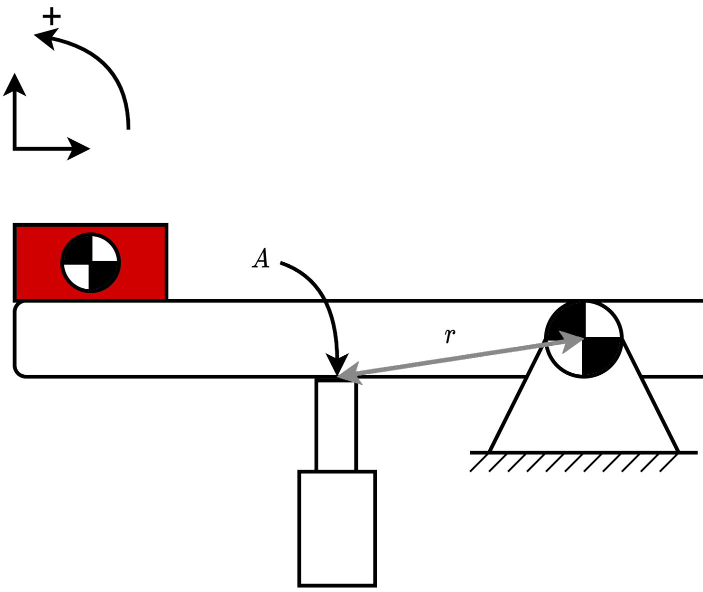


Figure 4.2: Cylinder and platform side view

Equation 4.5 is simplified, by Equation 4.7 and 4.6, to Equation 4.8. This equation was then used to calculate the effective mass from platform inertia and the distance from the platforms rotational axis to the cylinder head.

$$m_{eff} = \frac{2 \cdot E_{kin}}{\dot{y}_{cyl}^2} = \frac{2 \cdot \frac{1}{2} \cdot I_{eff} \cdot \dot{\theta}^2}{\left(r \cdot \dot{\theta}\right)^2} = \frac{I_{eff}}{r^2} \tag{4.8}$$

Multibody Approach

Using the multibody library the effective mass can also be derived. This is achieved by creating an accurate model of the platform, setting a constant cylinder force and measuring the resulting acceleration. The force and resulting acceleration at $t = 0$ is inserted into Equation 4.9. To ensure en accurate platform model and accurate results the platform data is extracted for the CAD model with appropriate material properties applied. A visualization of the platform was created from the geometric data from the CAD model, shown in 4.3

$$m_{eff} = \frac{\ddot{y}_{cyl}}{F_{cyl}} \tag{4.9}$$

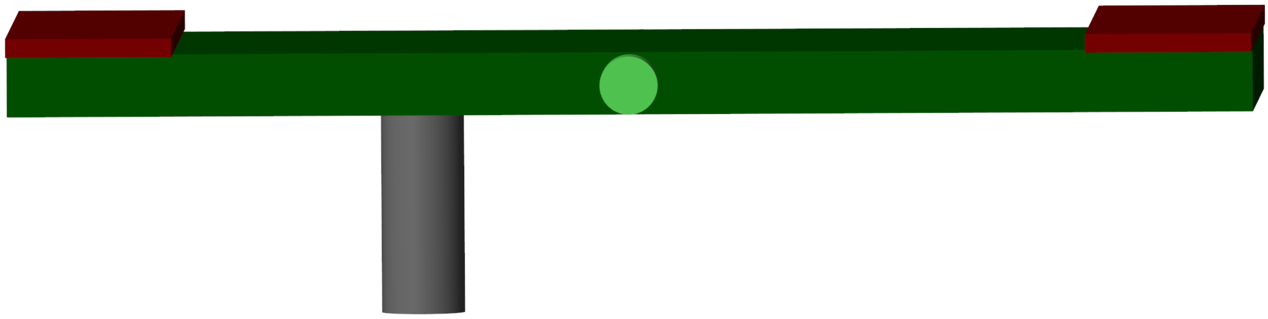


Figure 4.3: Multibody model of top frame, sideview

Energy & Multibody Comparison

The two methods are compared with four different configurations, configurations and results from either method are listed in Table 4.5. It can be noticed that both methods have a difference that is negligible with 4 decimals accuracy. Such negligible variations increases the confidence in the estimation and shows that the multibody model correctly captures the system dynamics. This accuracy is used to accept the results in Subsection 4.2.2.

Number of plates either side	m_{eff} energy method	m_{eff} multibody approach	% deviation
0	852.3831	852.3830	0%
1	1608.7726	1606.2004	0.15%
4	3877.1674	3875.5888	0.04%
6	5390.4645	5389.5536	0.02%

Table 4.5: Comparison between the energy and simscape method

4.2.2 Effective Applied Force

As part of the model simplification the external effective forces are computed as a single variable, calculated by Equation 4.10 [3]. Using the same accurate model constructed as for the effective mass estimation the effective external force, F_{ext}, can be computed by measuring the force required to keep the platform stationary such that Equation 4.11 can be simplified into Equation 4.12 and thus determining the external forces acting on the platform. The external forces specifically exclude the friction as this is covered separately in Section 4.4.

$$F_{ext} = -\frac{W_{ext}}{dx} \tag{4.10}$$

$$m_{eff} \cdot \ddot{y}_{cyl} = F_{cyl} - F_{ext} \tag{4.11}$$

$$F_{cyl} = F_{ext} \tag{4.12}$$

Symmetrical load on the platform was utilized such that F_{ext} equals $0N$ when the platform is level. To model this the external force is evaluated at 10° and Equation 4.13 used to represent the external force as a function of the platform angle.

$$F_{ext} = F_{ext,10^\circ} \cdot \left(\frac{\theta_{platform}}{10^\circ}\right) \tag{4.13}$$

$$\tag{4.14}$$

Table 4.7 lists the external force for each of the selected load configurations, both covered in the following subsection.

4.2.3 Selected Load Configurations

As mentioned in Subsection 4.2.2 symmetric load is utilized to have zero effective force while experiencing the system inertia. The client requested to test the system with 5 and 10 tonnes effective inertia. Table 4.6 lists the selected load configurations that are as close as possible to the desired loads, while keeping symmetrical load.

Number of plates (symmetric load)	Effective Load	Deviation % from requested load
5	4633.7 kg	7.9 %
12	9941.4 kg	-0.59 %

Table 4.6: Load Configurations

Number of plates (symmetric load)	Effective external force at 10 °
5	$794.5N$
12	$1727.7N$

Table 4.7: External force corresponding to Table 4.6

4.3 Platform Movement

The system and chosen configuration are required to follow sinusoidal motions. As suggested by relevant articles the interesting time periods are found between 12s-6s, specifically 6s, 8s, 10s and 12s periodic wave period [4]. From the client it was desired to test wave motions with period between 10s-4s, and sinusoidal wave motion for the 10s, 5, and 4s period was selected, and correspond to sinusoidal motions with $0.1Hz$, $0.2Hz$ and $0.25Hz$ frequency.

The wave amplitude and calculation of roll angle induced for any given wave motion is outside the scope of this thesis. Interesting roll angles are given to be 2°, 4° and 5°. Table 4.8 shows the local cylinder movement for each angle. The client desired every frequency to be tested for the 2° roll, $0.1Hz$ and $0.2Hz$ for 4 ° roll and 0.25 Hz with only 2 ° roll.

Desired angle	Corresponding cylinder movement
2	20 mm
4	35 mm
5	50 mm

Table 4.8: Angle - cylinder movement table

Following a sinusoidal motion is equal to that of wave motion, the principle that an oscillating platform on stable ground is equal and opposite to a stable platform with oscillating ground was applied to test wave compensation by following the sinusoidal motion. The greatest error during stable oscillations can further be used to find the wave compensation percentage, by Equation 4.15.

$$\text{Compensation } \% = \left(1 - \frac{error_{peak}}{wave_{peak}}\right) \cdot 100\% \tag{4.15}$$

4.4 Non-linear System Modeling

Non-linear system was constructed of the 2-pump circuit, configuration C in Section 2.3. This model was constructed both to test the implementation of control methods, experiment with how different parameters affect the system performance and to test system behavior with different reference types.

The servo valve and 1-pump circuit was, as mentioned in Subsections 3.2.4 and 3.2.5, found to not have the intended functionality. No non-linear models was constructed as no real data could be obtained to verify the accuracy of non-linear model(s). Both systems examined linearly in Sections 4.6 and 5.2.

Simulation Time Properties
Simulations was executed with a continuous fixed-step solver. It was decided to simulate systems with a first order forward-euler solver to keep the solver complexity simple. This required a sufficiently small time step to accurately simulate the system, the step time of 10^{-5} was implemented for all models. To decrease the simulation effort the simulation data was logged every 1 ms.

Friction & Energy Losses
As mentioned in Section 4.3 the platform movement is desired to be oscillating around zero. The hyperbolic friction model, Equation 4.16, is most useful for such scenarios where the velocity is nonzero, the current case with sine waves as reference signal [3].

The v_{tnh} constant was found to be 0.002 m/s, this value ensures a steep friction curve such that a smooth friction is kept. The small value of 0.002 was necessary as to capture the system friction even with a velocity on the mm/s magnitude. The effect of varying velocity parameter shown in Figure 4.4.

The friction constant, $\mu_k \cdot N$, is determined by comparing the simulated movement with real data. The friction coefficient of 70-130 N is found to best represent the system friction for step and sine responses.

$$F_{fric} = \mu_k \cdot N \cdot tanh\left(\frac{\dot{y}_{cylinder}}{v_{tnh}}\right) \tag{4.16}$$

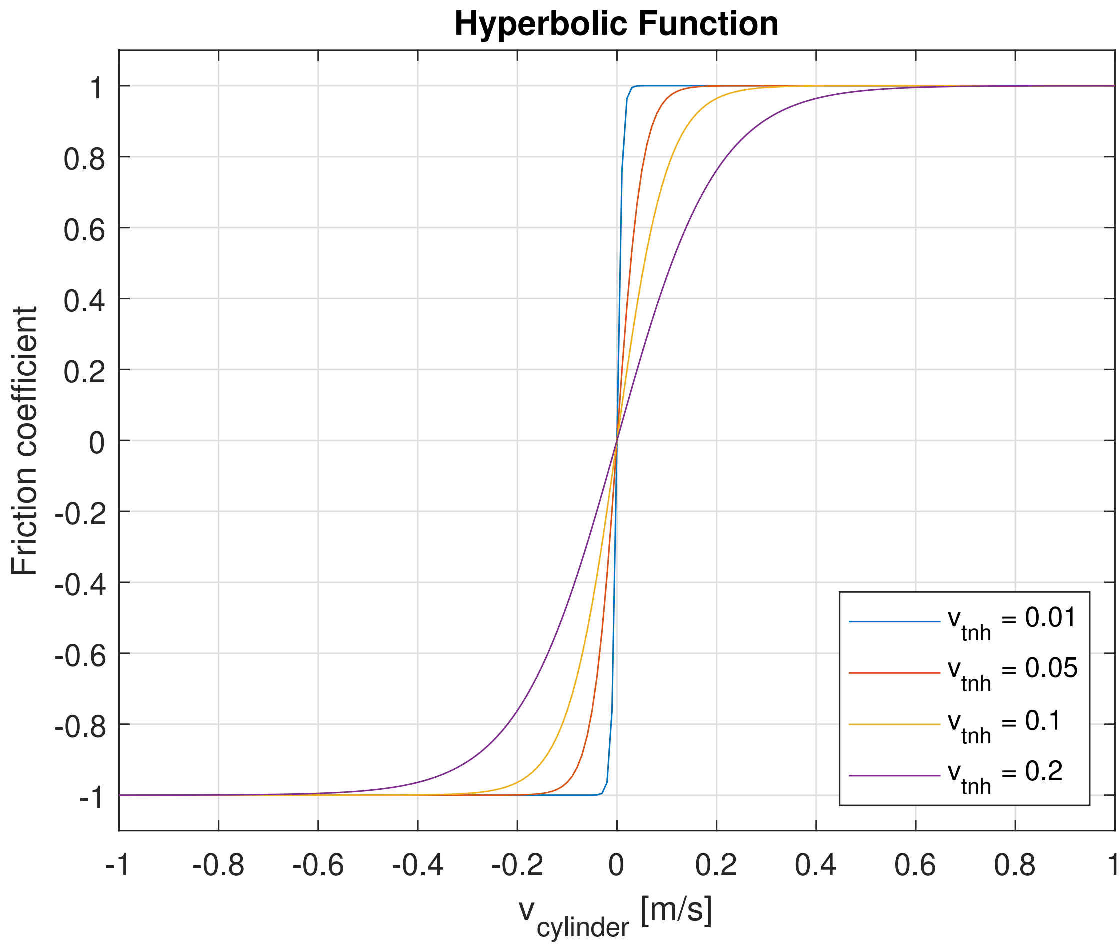


Figure 4.4: Illustration of different v_{tnh} values

Safety Valves

In the real system the safety valves have a response time of $\sim 2\ ms$ and are new, they are modeled as ideal by pressure saturation.

4.5 Non-linear 2-Pump Model

The 2-pump circuit model was constructed to be an accurate representation of the real system while maintaining the system model simple. A simpler model favors easy troubleshooting and may only differ slightly from the real system if the system is fully understood. Each system part was thus analyzed separately to understand key elements to accurately model. Figure 4.5 shows the system schematic with all system parts.

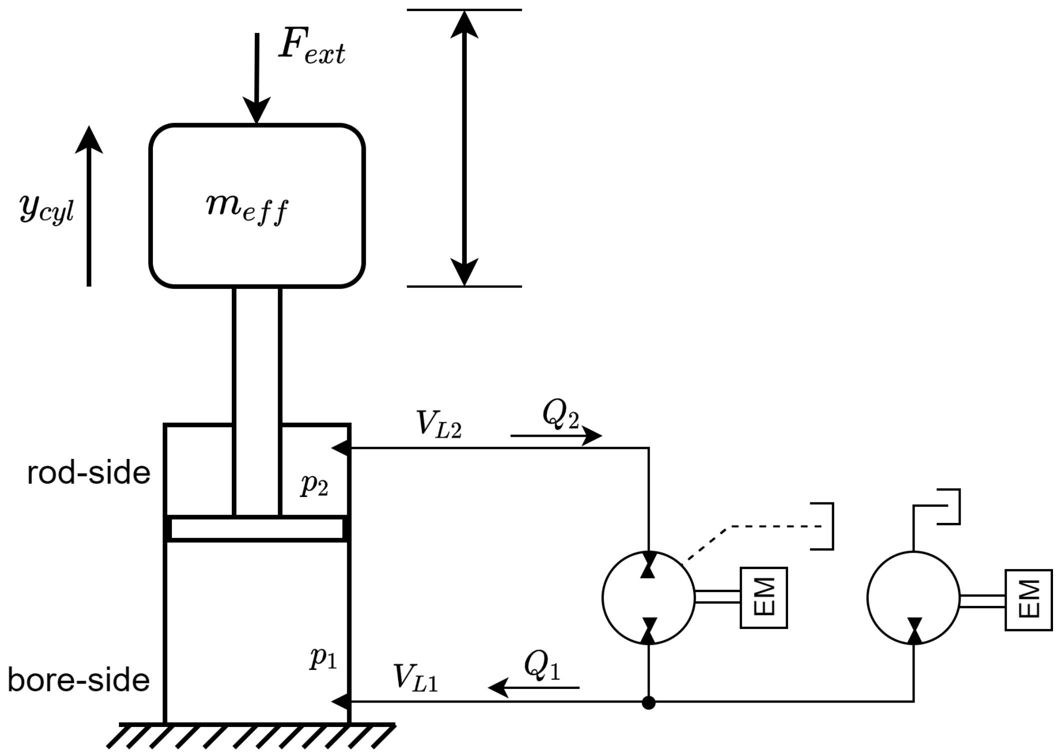


Figure 4.5: 2-Pump System

4.5.1 Hydraulic Cylinder

The hydraulic cylinder, and platform are simplified in Section 4.2, with the simplification repeated in Equation 4.17. Key element is to correctly approximate the friction constant in the implemented sliding friction.

$$m_{eff} \cdot \ddot{y} = p_1 \cdot A_1 - p_2 \cdot A_2 - F_{ext} - F_{fric} \tag{4.17}$$

4.5.2 Effective Bulk Modulus

The bulk modulus for the vg 46 oil is approximately 1.6e9 Pa at the operation temperature of 30 °C, extracted from Matlabs hydraulic database [12]. Aforementioned data is appended in Appendix A.1

From the effective bulk modulus formula, Equation 4.18, it can be noted that the ratio of gas ϵ_g greatly affects the effective bulk modulus in the system [1]. An exact estimate of the gas percentage is difficult to accurately estimate and must be measured for accurate results [5].

The bulk modulus was estimated such that the closed loop response for the model corresponded to the real data, with a preferred conservative approach. A conservative approach was preferred, estimating a lower gas percentage effectively results in a greater stiffness which could lead to unrealistic expectations for system stiffness and stability.

$$\beta_{eff} = \frac{1}{\frac{1}{\beta_L} + \frac{\epsilon_g}{p^{(abs)}}} \tag{4.18}$$

Figure 4.18 shows how the effective bulk modulus varies for multiple entrapped air percentages as a function of system pressure.

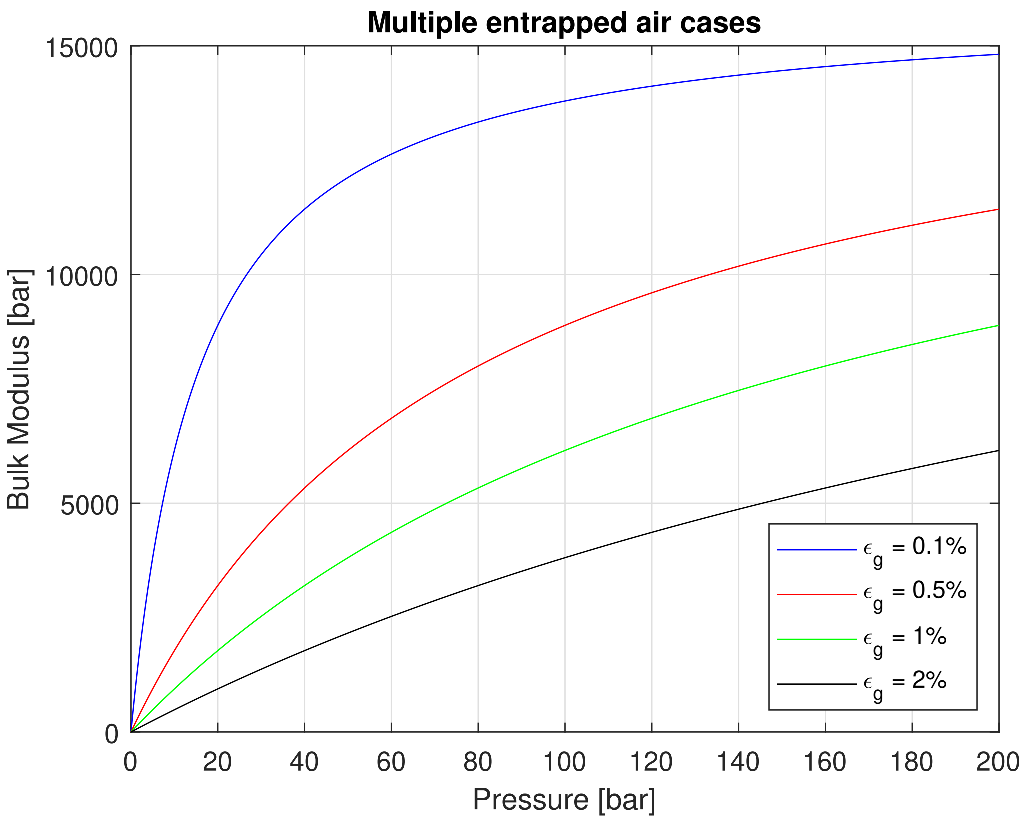


Figure 4.6: Effective Bulk Modulus

The final ϵ_g was estimated to be 4% by comparing the model stiffness to the real model. Resulting in a bulk modulus of 120-200 bar at 4-6 bar.

4.5.3 Pump efficiency

The pump efficiency for the second pump is given in its datasheet, shown in Figure 4.7 [2]. The volumetric efficiency was implemented as constant 0.9 for the secondary pump, from the relative low operating pressure.

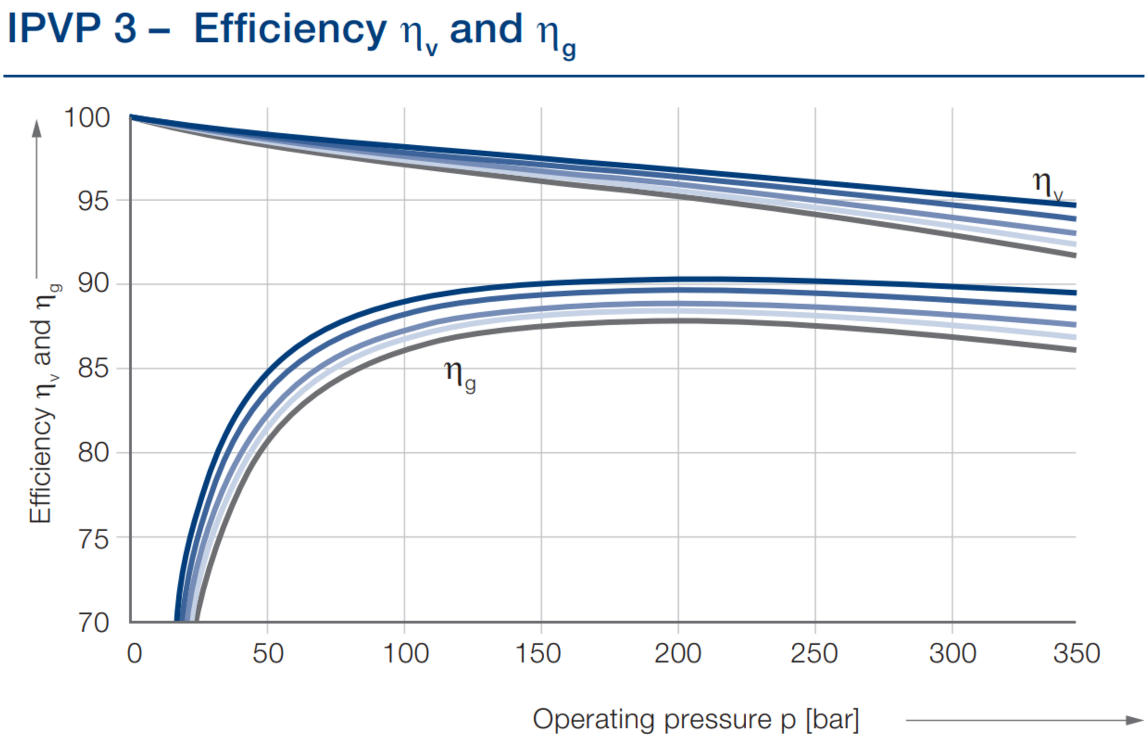


Figure 4.7: Pump efficiency curve

The primary pumps datasheet lists no efficiency value or table, only that it is a high efficiency pump. The same constant 90% volumetric efficiency was implemented.

4.5.4 Pump Leakage

Two types of leakage will be considered, leakage of the primary pump (a piston pump) and leakage of the secondary pump (a gear pump). By observing the system three different leakage paths are found, 1) Leakage across the piston pump (i.e. from high pressure to low pressure side), 2) leakage from piston pump to drain and 3) leakage over gear pump (bore-pressure to tank).

Leakage type 1) will be considered laminar, as suggested by "Michael Rygaard Hansen" in "Hydraulic Components and Systems" [2]. As the leakage is considered laminar the leakage, Equation 4.19, can be implemented to capture the leakage across the pump, with C_1 representing the leakage in volume/(time · pressure).

[2]Full datasheet appended in Appendix C.5. η_v shows the volumetric efficiency and η_g shows the overall efficiency

$$Q_{leak,1} = C_{leak,1} \cdot \Delta P \tag{4.19}$$

Leakage path 2) and 3) was combined as both methods essentially ensures that oil in the system ends up in the tank. This assumption was deemed acceptable as both leakage type 2) and 3) ensures that the system oil is drained with stationary motors, which is the case for the real system. Similarly to leakage 1) a laminar flow model was assumed however only as a function of the bore-pressure. Suggesting that there exist no leakage from the rod-side to drain, which is not the case for the real system. This is accounted for indirectly by Equation 4.19 as any pressure differential between the bore- and rod-side will be equalized. Equation 4.20 is the equation constructed to model flow out of the system.

$$Q_{leak,2} = C_{leak2} \cdot p_1 \tag{4.20}$$

It is worth noting that both leakage equations both must be tuned such that the simulation data corresponds with obtained data from the real system, especially considering that the leakage varies depending on the motor speeds. To account for this the leakage parameters are adjusted depending if the simulation is a step-response or sine-wave, i.e. greater leakage when closer to 0 *rpm*. Typical leakage in 4.9.

Leakage parameter	Typical value	Optimized for
C_1	1.8e-10 $m3/(s \cdot Pa)$	General accuracy
C_2	7.3e-11 $m3/(s \cdot Pa)$	General accuracy

Table 4.9: Leakage parameter table

4.5.5 EL-Motor & Response

As the primary objective is to model the flow delivered by the pump the el-motor dynamics was simplified to a simple 1st order transfer function. The step response of the motor shown in Figure 4.8, with the transfer function in Equation 4.21.

$$G_{motor}(s) = \frac{1}{0.04s + 1} \tag{4.21}$$

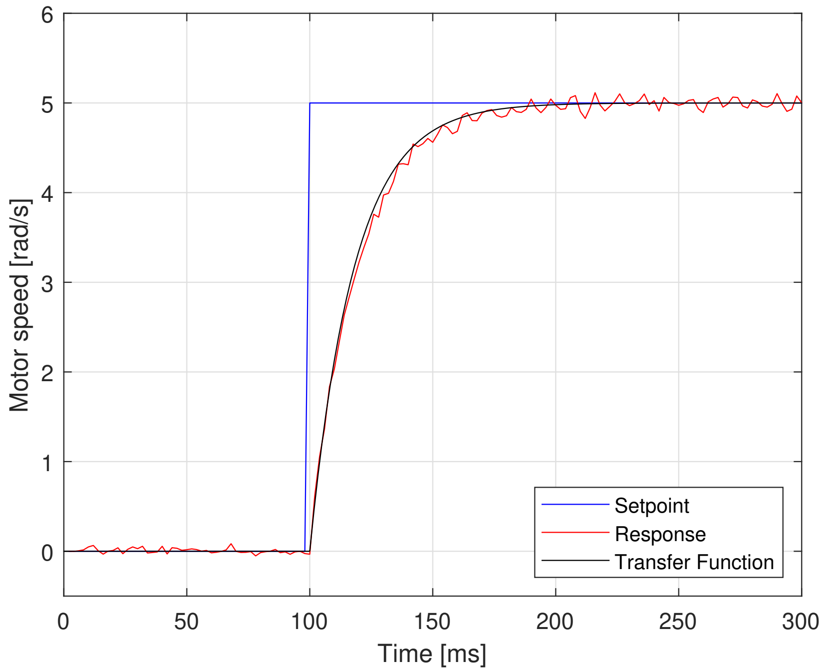


Figure 4.8: Step response and transfer function same figure

Both motors are such that they can deliver 12.5 Nm continuously, roughly equivalent to a ΔP of 20 bar, stall at $\sim$ 25 bar ΔP.[3] In the model it was assumed that the pressure differential over the motor would not be great enough to induce motor stall, this assumption was verified up towards the real system.

If pump stall was present in the real system it would have been put emphasis on capturing this in the model trough limiting the motor power and implementing the real life speed-torque curve.

[3]The exact torque will depend on the mechanical efficiency and displacement of the pump (here: 6 cm^3). The efficiency is assumed to be 1.0 is order to get an estimation of the stall pressure values

4.5.6 Model Simulation

The non-linear 2-pump model was simulated using Simulink, the model-based part of Matlab. The simulation model was constructed using Equations 4.22 to 4.29, directions and labels in Figured 4.5. A visual example of the simulink model is shown in Figure 4.9, where the block-diagram design can be seen. The specific part shown is the mechanical model and is used to calculate the actuator head position. The nonlinear model is constructed from Equation 4.22 to 4.29, which are the equations describing the system.

$$\dot{p}_1 = \frac{\beta_1}{V_1} \cdot (Q_1 - \dot{y} \cdot A_1) \tag{4.22}$$

$$\dot{p}_2 = \frac{\beta_2}{V_2} \cdot (-Q_2 + \dot{y} \cdot A_2) \tag{4.23}$$

$$\ddot{y} \cdot m_{eff} = p_1 \cdot A_1 - p_2 \cdot A_2 - F_{ext} - F_{fric} \tag{4.24}$$

$$Q_1 = Q_p + Q_s = n_p \cdot \eta_{V,p} \cdot D_p + n_s \cdot \eta_{V,s} \cdot D_s \tag{4.25}$$

$$Q_2 = Q_p = n_p \cdot \eta_{V,p} \cdot D_p \tag{4.26}$$

$$V_1 = V_{line1} + A_1 \cdot y \tag{4.27}$$

$$V_2 = V_{line2} + A_2 \cdot (y_{max} - y) \tag{4.28}$$

$$\beta_n = \frac{1}{\frac{1}{\beta_L} + \frac{\epsilon_g}{p_n^{(abs)}}} \tag{4.29}$$

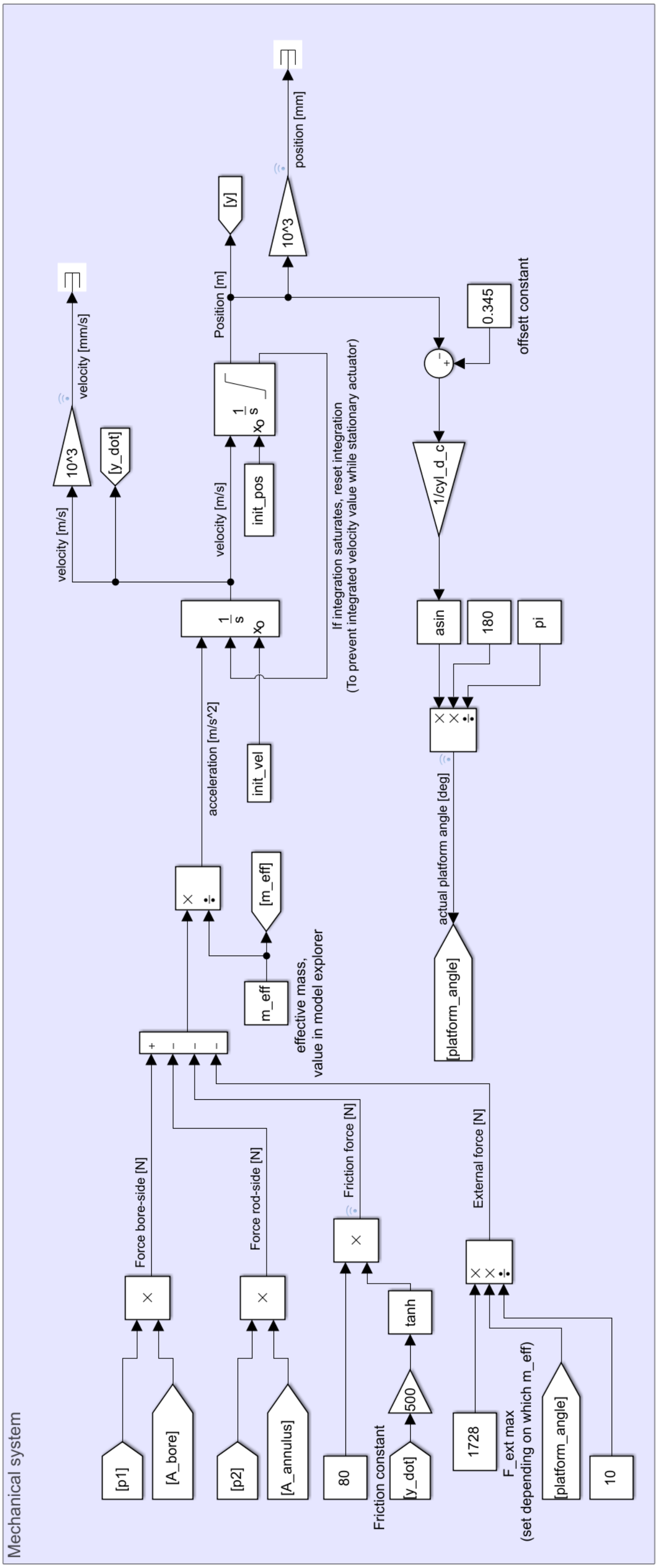


Figure 4.9: Mechanical Simulation in Simulink

4.6 Linear Servo Valve Model

A linear model of the servo valve system in Figure 4.10 was constructed such that a transfer function be constructed and stability margins of the servo circuit can be examined by bode plot. The transfer function describing the system is the relation between the valve opening, y, and the cylinder position y.

Examination of system stability margins is deemed key as there is no reliable obtainable data and such only stability margins can be compared for the circuit with that of the 2-pump circuit.

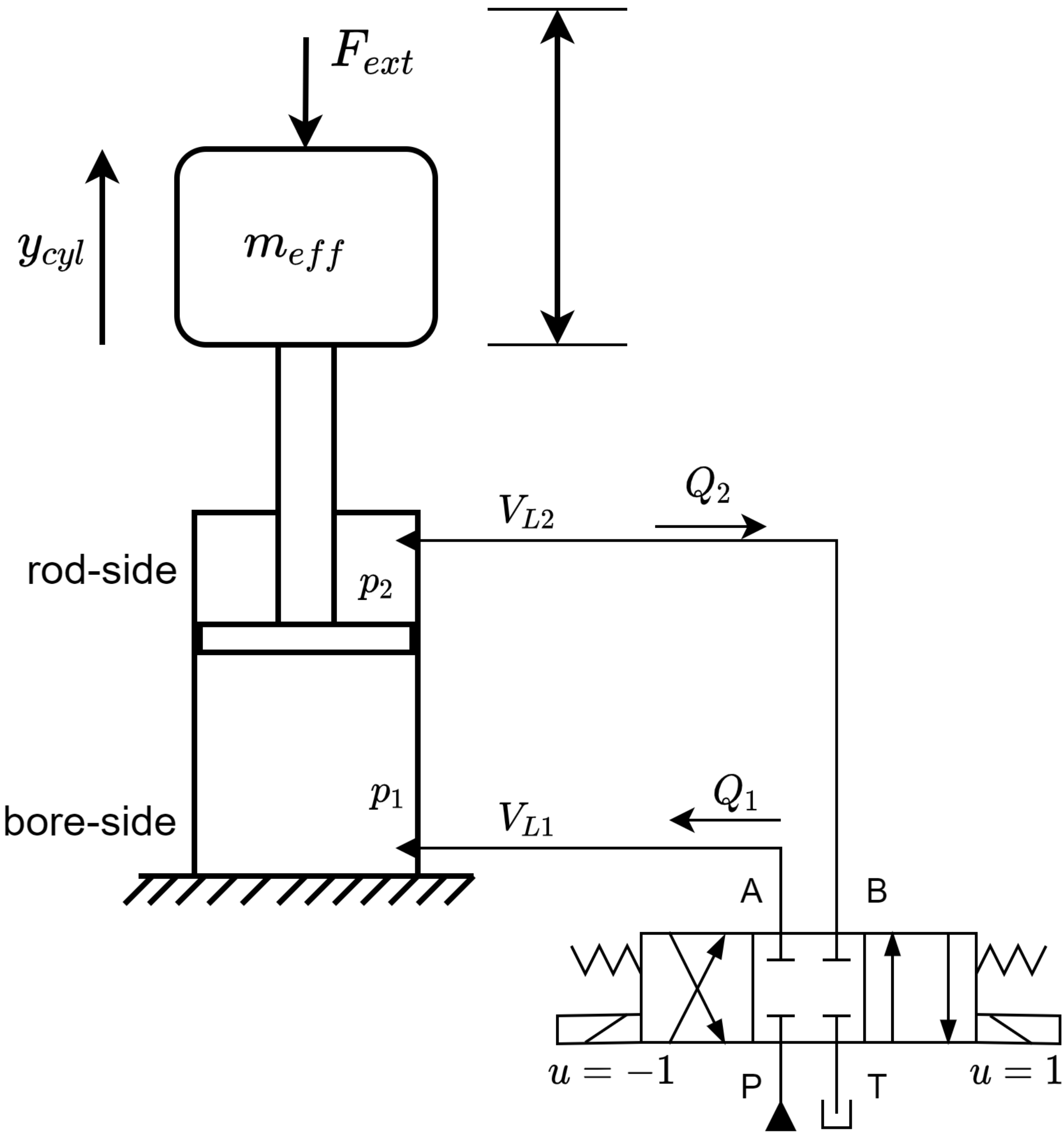


Figure 4.10: Servo valve System

4.6.1 Linearizing Orifice Equation

The non-linear orifice equation is linearized, Equation 4.30, and defined as a function of Δu and Δp. The Δ operator is used to indicate the variables deviation from which point the model is linearized, this notation is omitted for notional simplicity. Equations 4.31 and 4.32 are respectively the definition for flow gain, K_{qu}, and flow-pressure gain, K_{qp}, where the nl subscript refers to the initial orifice equation [7].

The steady state leakage was included by computing leakage for a steady state opening from 0.002 to 0.05 [2]. The chosen steady state value of 0.01 as the valve was serviced and could be expected to feature a small steady state leakage. The steady state leakage coefficient are not shown in the derivation but can be observed as a constant term to Equations 4.35, 4.40 4.39 and 4.40.

$$Q = K_{qu} \cdot \Delta u - K_{qp} \cdot \Delta p \tag{4.30}$$

$$K_{qu} = \frac{\partial Q_{nl}}{\partial u}|_{ss} \tag{4.31}$$

$$K_{qp} = -\frac{\partial Q_{nl}}{\partial p}|_{ss} \tag{4.32}$$

The flow gain and flow-pressure gain coefficients are evaluated separately for the extension and retraction case. The extension case is evaluated below;

Extension ($u \geq 0$)
For extension the valve is such that $p_s \rightarrow p_1$ & $p_2 \rightarrow p_T$, the assumption is that $p_s > p_1$ & $p_2 > p_T$ during the entire extension.

Flow gain equations:

$$K_{qu1,ext} = \frac{\partial Q_{nl,1}}{\partial u} = \frac{\partial}{\partial u}\left(C_d \cdot A_{d,max} \cdot u \cdot \sqrt{\frac{2}{\rho} \cdot (p_s - p_1)}\right)|_{ss}$$

$$K_{qu1,ext} = C_d \cdot A_{d,max} \cdot \sqrt{\frac{2}{\rho} \cdot (p_s - p_{1,ss})} \tag{4.33}$$

$$K_{qu2,ext} = \frac{\partial Q_{nl,2}}{\partial u} = \frac{\partial}{\partial u}\left(C_d \cdot A_{d,max} \cdot u \cdot \sqrt{\frac{2}{\rho} \cdot (p_2 - p_T)}\right)|_{ss}$$

$$K_{qu2,ext} = C_d \cdot A_{d,max} \cdot \sqrt{\frac{2}{\rho} \cdot (p_{2,ss} - p_T)} \tag{4.34}$$

Flow-pressure gain equations:

$$K_{qp1,ext} = -\frac{\partial Q_{nl}}{\partial p_1}|_{ss} = -\frac{\partial}{\partial p_1}\left(C_d \cdot A_{d,max} \cdot u \cdot \sqrt{\frac{2}{\rho} \cdot (p_s - p_1)}\right)$$

$$= -\frac{1}{2} \cdot C_d \cdot A_{d,max} \cdot u_{ss} \cdot \left(-\frac{2}{\rho}\right) \cdot \frac{1}{\sqrt{\frac{2}{\rho} \cdot (p_s - p_{1,ss})}}$$

$$= C_d \cdot A_{d,max} \cdot u_{ss} \cdot \frac{1}{\sqrt{\rho^2}} \cdot \frac{1}{\sqrt{\frac{2}{\rho} \cdot (p_s - p_{1,ss})}}$$

$$K_{qp1,ext} = \frac{C_d \cdot A_{d,max} \cdot u_{ss}}{\sqrt{2 \cdot \rho \cdot (p_s - p_{1,ss})}} + 5.5249e - 13 \tag{4.35}$$

$$K_{qp2,ext} = -\frac{\partial Q_{nl}}{\partial p_2}|_{ss} = \frac{C_d \cdot A_{d,max} \cdot u_{ss}}{\sqrt{2 \cdot \rho \cdot (p_{2,ss} - p_T)}} + 5.5249e - 13 \tag{4.36}$$

Retraction ($u < 0$)
For extension the valve is such that $p_s \rightarrow p_2$ & $p_1 \rightarrow p_T$ and it is assumed that $p_s > p_2$ & $p_1 > p_T$ during the retraction period. The derivations are similar to the extension scenario with the difference being that a minus sign is included in Equations 4.39 and 4.40. This inclusion is to ensure that the K_{qp} values for retraction are positive even as the sign of u_{ss} becomes negative, as it does for the retraction case.

$$K_{qu1,ret} = C_d \cdot A_{d,max} \cdot \sqrt{\frac{2}{\rho} \cdot (p_{1,ss} - p_T)} \tag{4.37}$$

$$K_{qu2,ret} = C_d \cdot A_{d,max} \cdot \sqrt{\frac{2}{\rho} \cdot (p_s - p_{2,ss})} \tag{4.38}$$

$$K_{qp1,ret} = -\frac{C_d \cdot A_{d,max} \cdot u_{ss}}{\sqrt{2 \cdot \rho \cdot (p_{1,ss} - p_T)}} + 5.5249e - 13 \tag{4.39}$$

$$K_{qp2,ret} = -\frac{C_d \cdot A_{d,max} \cdot u_{ss}}{\sqrt{2 \cdot \rho \cdot (p_s - p_{2,ss})}} + 5.4986e - 13 \tag{4.40}$$

4.6.2 Governing Equations

The governing equations are the equations for flow trough servo valve, Equation 4.41 and 4.42, pressure gradient equations for respectively the bore- and rod-side, Equation 4.43 and 4.44, as well as the sum of forces for the cylinder, Equation 4.45. The definition of Q_2 in Equation 4.42 is modified from the original expression, Equation 4.30. This is to account for the correct flow direction and magnitude, the flow definition is shown in Figure 4.10.

$$Q_1 = K_{qu,1} \cdot u - K_{qp,1} \cdot p_1 \tag{4.41}$$

$$Q_2 = K_{qu,2} \cdot u + K_{qp,2} \cdot p_2 \tag{4.42}$$

$$\dot{p}_1 = \frac{\beta}{V_1} \cdot (Q_1 - \dot{y} \cdot A_1) \tag{4.43}$$

$$\dot{p}_2 = \frac{\beta}{V_2} \cdot (-Q_2 + \dot{y} \cdot A_2) \tag{4.44}$$

$$m \cdot \ddot{y} = p_1 \cdot A_1 - p_2 \cdot A_2 - d \cdot \dot{y} - F_{ext} \tag{4.45}$$

The volumes in Equation 4.43 and 4.44 are a function of the cylinder stroke, y. For simplifications the volumes are considered constant and examined around the point at which the cylinder stroke results in a level platform, as the platform reference motion will deviate equally in positive and negative angle. The assumptions for the bulk modulus are briefly discussed in Subsection 4.6.3 as they are more intricate.

4.6.3 Bulk Modulus Consideration

The bulk modulus will vary as a function of the system pressure and the presence of air in the system. As mentioned in "Hydraulic Control Systems" By Merrit there are certain bulk modulus values more reliable than others, such as the bulk modulus equal to 7000 *bar* for high pressure systems.

A typical servo valve system will typically have $\sim p_s/2$ steady state pressure on either side [11], roughly 100 *bar* for this system. Thus the steady state pressures are expected to be greater than those mentioned by Merrit, indicating that the bulk modulus of 7000 *bar* can be implemented with out consideration. For this liquid the bulk modulus of 7000 *bar* suggests $\sim$ 0.3-0.8% entrapped air in this system at 70 *bar*.

4.6.4 Servo valve Dynamics

The datasheet for the Moog D63 valve is used to construct a 2nd order unit gain transfer function to model the valve dynamics.

From the datasheet in Appendix C.1 it is observed that the valves step response indicates critically damped response with a apparent natural frequency of 90 Hz, equal to 565.5 rad/s. Equation 4.46 was thus constructed to model the valve dynamic.

$$
\begin{aligned}
G_v &= \frac{U(s)}{I(S)} = \frac{1}{\frac{1}{\omega^2} \cdot s^2 + \frac{2 \cdot \zeta}{\omega} \cdot s + 1} \\
G_v &= \frac{1}{3.127 \cdot 10^{-6} s^2 + 0.003537 s + 1}
\end{aligned}
\tag{4.46}
$$

4.6.5 Servo Valve & Mechanical Stability

In order to avoid performance impact the valve frequency should be at least three times that of the connected mechanical system [7]. Natural frequency for a linear actuator with mass is found by Equations 4.47, this equation can be applied here as the system simplification is performed [7]. By inserting the real parameters it was observed that the servo valve does not impact the system stability until the bulk modulus approaches $1bar$, an unreasonable bulk modulus for the servo system. Thus it can be concluded the valve does not impact system performance.

$$
\begin{aligned}
\omega_{mh} &= \frac{A_2}{\sqrt{m_{eff} \cdot C}} \\
C &= \frac{V_0}{4 \cdot \beta} \\
V_0 &= A_2 \cdot y_{max} + 2 \cdot V_{line}
\end{aligned}
\tag{4.47}
$$

4.6.6 Laplace Conversion

The laplace conversions of the governing equations are Equations 4.50 trough 4.52. Equations 4.50 and 4.51 have been re-written such that the flow Q_1 and Q_2 are isolated

Taking laplace transform of the linear governing assume zero initial conditions, listed below:

$$Q_1(s) = K_{qu,1} \cdot U(s) - K_{qp,1} \cdot P_1(s) \tag{4.48}$$

$$Q_2(s) = K_{qu,2} \cdot U(s) + K_{qp,2} \cdot P_2(s) \tag{4.49}$$

$$Q_1(s) = \frac{V_1}{\beta} \cdot sP_1(s) + A_1 \cdot sY(s) \tag{4.50}$$

$$Q_2(s) = -\frac{V_2}{\beta} \cdot sP_2(s) + A_2 \cdot sY(s) \tag{4.51}$$

$$m \cdot s^2 Y(s) = P_1(s) \cdot A_1 - P_2(s) \cdot A_2 - d \cdot sY(s) - F_{ext} \tag{4.52}$$

Equating the right hand side of respectively Equation 4.48 & 4.50, and Equation 4.49 & 4.51:

$$K_{qu,1} \cdot U(s) - K_{qp,1} \cdot P_1(s) = \frac{V_1}{\beta} \cdot sP_1(s) + A_1 \cdot sY(s) \tag{4.53}$$

$$K_{qu,2} \cdot U(s) + K_{qp,2} \cdot P_2(s) = -\frac{V_2}{\beta} \cdot sP_2(s) + A_2 \cdot sY(s) \tag{4.54}$$

The rearranging of equations above are listed below:

$$\frac{V_1}{\beta} \cdot sP_1(s) + K_{qp,1} \cdot P_1(s) = K_{qu,1} \cdot U(s) - A_1 \cdot sY(s) \tag{4.55}$$

$$\frac{V_2}{\beta} \cdot sP_2(s) + K_{qp,2} \cdot P_2(s) = K_{qu,2} \cdot U(s) - A_2 \cdot sY(s) \tag{4.56}$$

Further the equations above are rearranged and isolated with respect to the pressures. The derivations are listed below with the equations representing $P_1(s)$ and $P_2(s)$ are respectively Equations 4.57 and 4.58

$$P_1(s) \cdot \left(\frac{V_1}{\beta} \cdot s + K_{qp,1} \right) = K_{qu,1} \cdot U(s) - A_1 \cdot sY(s)$$
$$P_1(s) = \frac{1}{\left(\frac{V_1}{\beta} \cdot s + K_{qp,1} \right)} \cdot (K_{qu,1} \cdot U(s) - A_1 \cdot sY(s)) \tag{4.57}$$
$$P_2(s) \cdot \left(\frac{V_2}{\beta} \cdot s + K_{qp,2} \right) = -K_{qu,2} \cdot U(s) + A_2 \cdot sY(s)$$
$$P_2(s) = \frac{1}{\left(\frac{V_2}{\beta} \cdot s + K_{qp,2} \right)} \cdot (-K_{qu,2} \cdot U(s) + A_2 \cdot sY(s)) \tag{4.58}$$

The servo valve transfer function is Equation 4.46 from Subsection 4.6.4, repeated in Equation 4.59.

$$G_v = \frac{1}{3.127 \cdot 10^{-6} s^2 + 0.003537s + 1} \tag{4.59}$$

4.6.7 Transfer Function

The system block diagram in Figure 4.11 was constructed from Equations 4.52, 4.57, 4.58 and 4.59. The systems transfer function, Equation 4.60, is derived by simplifying the block diagram and using matlab simplification functionality. The numerator and denominator expressions are listed in Equation 4.61 trough 4.66. The full block diagram simplification and transfer function derivation can be found in Appendix 4.60. Explanation of symbols and symbol values in Table 4.10

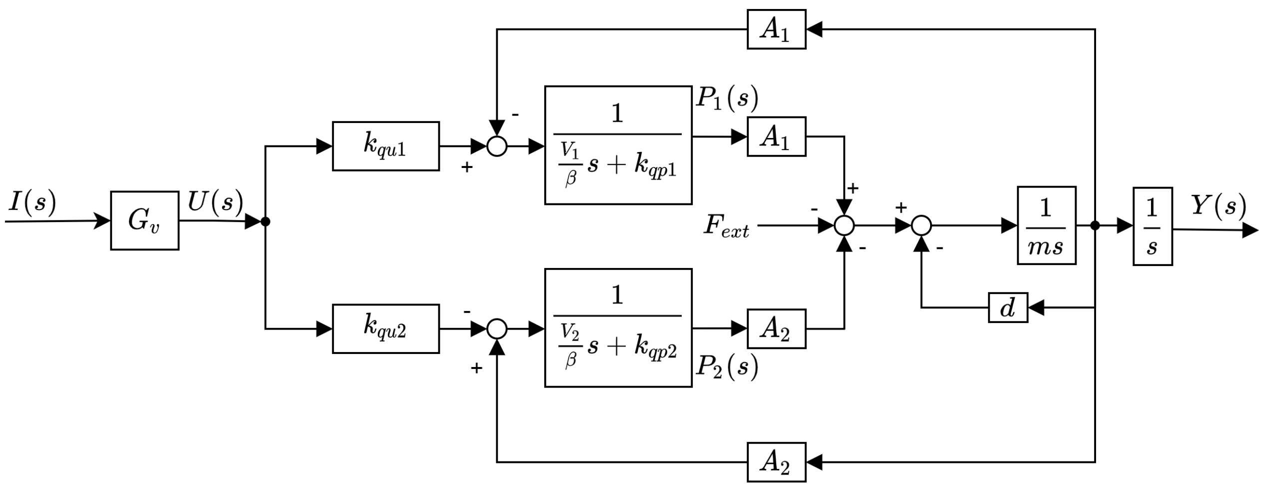


Figure 4.11: System Blockdiagram

$$G_{sys}(s) = \frac{Y(s)}{I(s)} = \frac{N_1 s + N_0}{s\left(D_3 s^3 + D_2 s^2 + D_1 s + D_0\right)} \tag{4.60}$$

$$N_1 = A_1 K_{qu1} V_2 \beta + A_2 K_{qu2} V_1 \beta \tag{4.61}$$

$$N_0 = A_1 K_{qp2} K_{qu1} \beta^2 + A_2 K_{qp1} \cdot K_{qu2} \beta^2 \tag{4.62}$$

$$D_3 = V_1 V_2 m \tag{4.63}$$

$$D_2 = V_1 V_2 + K_{qp1} V_2 \beta m + K_{qp2} V_1 \beta m \tag{4.64}$$

$$D_1 = A_1^2 V_2 \beta + A_2^2 V_1 \beta + K_{qp1} K_{qp2} \beta^2 m + K_{qp1} V_2 \beta d + K_{qp2} V_1 \beta d \tag{4.65}$$

$$D_0 = K_{qp2} A_1^2 \beta^2 + K_{qp1} A_2^2 \beta^2 + K_{qp1} K_{qp2} d \beta^2 \tag{4.66}$$

Symbol	Value	Description/Comment
A_1	$0.0031172 m^2$	Bore side area
A_2	$0.0020994 m^2$	Rod side area
V_1	$0.0012027 m^3$	Bore side volume
V_2	$0.00045264 m^3$	Rode side volume
β	7e8 Pa	Bulk Modulus
$C_d \cdot A_{d,max}$	$7.3463 \cdot 10^{-6} m^2$	Max flow coefficient
ρ	850 kg/m^3	Oil density
$p_{s,ss}$	210e5 Pa	Steady state tank pressure
$p_{t,ss}$	1e5 Pa	Steady state supply pressure
K_{qu1}	-	Flow gain coefficient
K_{qu2}	-	Flow gain coefficient
K_{qp1}	-	Flow-pressure gain coefficient
K_{qp2}	-	Flow-pressure gain coefficient

Table 4.10: Value & symbol description

The flow gain and flow-pressure coefficient are covered in Section 4.6.

The bulk modulus, β, and system pressures, p_1, p_2, vary during system operation. For the linearization these values are all set constant, the bulk modulus discussed in Subsection 4.6.3 and the system pressures are assumed to follow normal valve leakage and be $\sim p_{supply}/2$ [11].

4.7 Linear 1-Pump Model

Both volumes are regarded as constant with the stroke length corresponding to a level platform, with the bulk modulus for the 1-pump circuit discussed in Subsection 4.7.2. The laplace conversion is covered in Subsection 4.7.3. The motor dynamics neglected to simplify the final transfer function and maximum flow by input of 1.

The assumptions differ for the extension and retraction case as the accumulators shown in Section 2.2 are utilized to keep either the rod side constant for extension and bore side constant for retraction. The accumulators ensure constant pressure even with leakage over the pump, and the leakage out of the system is modeled as laminar and dependent on the varying system pressure. The leakage coefficient is set to the one utilized for the similar case for the 2-pump non-linear model, $8e - 11m^3/s/(Pa)$

4.7.1 Governing Equations

$$Q_p = V_p \cdot n_{p,max} \cdot \eta_{vol,p} \tag{4.67}$$

$$\dot{p}_1 = \frac{\beta}{V_1} \cdot (Q_p - \dot{y} \cdot A_1) \tag{4.68}$$

$$\dot{p}_2 = \frac{\beta}{V_2} \cdot (-Q_p + \dot{y} \cdot A_2) \tag{4.69}$$

$$m \cdot \ddot{y}_{cyl} = p_1 \cdot A_1 - p_2 \cdot A_2 - F_{ext} - F_{friction} \tag{4.70}$$

4.7.2 Bulk Modulus Considerations

Equal bulk modulus of 150 bars was considered for this model, from the non-linear 2-pump model discussed in Subsection 4.5.2.

4.7.3 Laplace Conversion

Similarly to the servo valve system the 1-pump system can be analyzed by a transfer function describing the relation between motor speed, n_p, and cylinder position, y. The governing equation in s-domain are listed below.

The friction is linearized to be proportional with velocity and external force is disturbance input and negligible, initial conditions assumed to be 0.

$$Q_p(s) = V_p \cdot N_p(s) \cdot \eta_{vol,p} \tag{4.71}$$

$$P_1(s) \cdot s = \frac{\beta}{V_1} \cdot (Q_p(s) - s \cdot Y(s) \cdot A_1) \tag{4.72}$$

$$P_2(s) \cdot s = \frac{\beta}{V_2} \cdot (-Q_p(s) + s \cdot Y(s) \cdot A_2) \tag{4.73}$$

$$m \cdot s^2 \cdot Y(s)_{cyl} = P_1(s) \cdot A_1 - P_2(s) \cdot A_2 - F_{friction} \tag{4.74}$$

4.7.4 Transfer function - Extension

Construction of the transfer function is achieved by constructing block diagrams of the laplace conversion and simplifying. The initial system, Figure 4.12, is reduced to its final form, Figure 4.13, where matlab was utilized to calculate the resulting transfer function. The stability analysis in 5.2

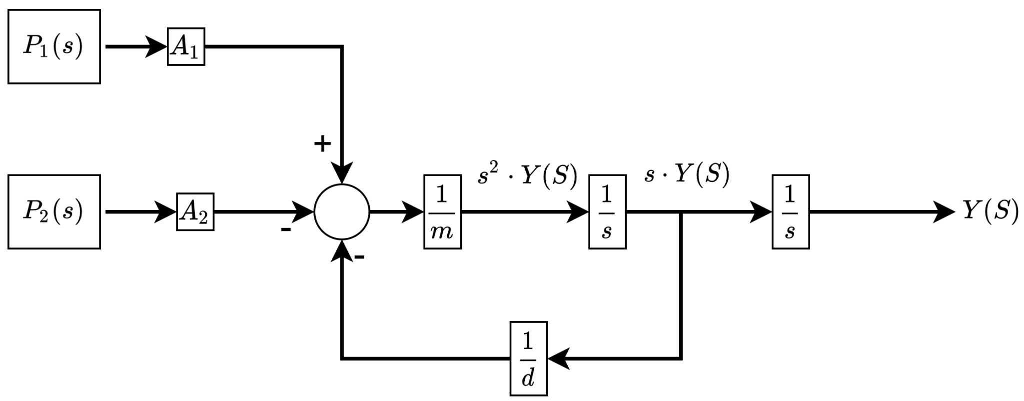


Figure 4.12: Initial block diagram

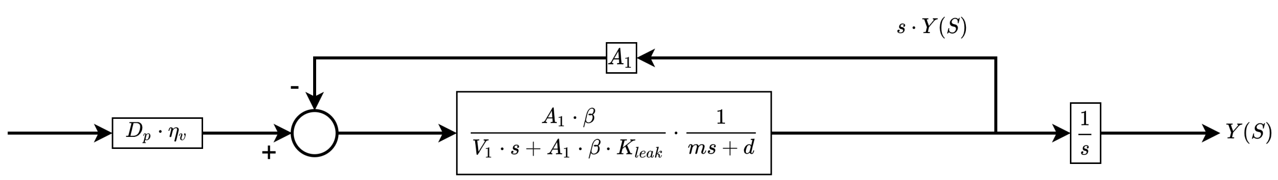


Figure 4.13: Final block diagram

The resulting transfer function in Equation 4.75 and Table 4.11 . The input of 100 π for max motorspeed setpoint.

$$G(s) = \frac{N0}{s(D2s^2 + D1s + D0)} \tag{4.75}$$

Parameter	Value
N0	$A_1 \cdot \beta \cdot D_p \cdot \eta_p$
D2	$V_1 \cdot m_{eff}$
D1	$V_1 \cdot d + A_1 \cdot \beta \cdot K_{leak} \cdot m_{eff}$
D0	$\beta \cdot A_1^2 + \beta \cdot K_{leak} \cdot d \cdot A_1$

Table 4.11: Extension transfer function table

4.7.5 Transfer function - Retraction

For retraction the same initial block diagram was utilized and the final form shown in Figure 4.14.

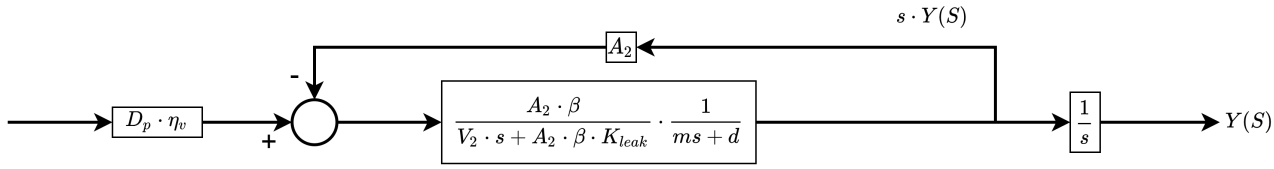


Figure 4.14: Final form retraction

The resulting transfer function in Equation 4.76 and Table 4.12. The input of 100 π for max motor speed setpoint, signs are accounted for that positive reference results in retraction. This was done to achieve a transfer function with similar form to that of extension and if negative motor speed is utilized the resulting feedback is positive rather than negative.

$$G(s) = \frac{N0}{s(D2s^2 + D1s + D0)} \tag{4.76}$$

Parameter	Value
N0	$A_2 \cdot \beta \cdot D_p \cdot \eta_p$
D2	$V_2 \cdot m_{eff}$
D1	$V_2 \cdot d + A_2 \cdot \beta \cdot K_{leak} \cdot m_{eff}$
D0	$\beta \cdot A_2^2 + \beta \cdot K_{leak} \cdot d \cdot A_2$

Table 4.12: Retraction transfer function table

Chapter 5

Analysis

5.1 Servo valve Stability Margins

The bode plot for extension and retraction are shown in Figure 5.1 and 5.2, the bode plots was constructed by the transfer function from Subsection 4.6.7. The bode diagram was constructed for the 900kg system and default leakage, diagrams with varying leakage in Subsections 5.1.2 and 5.1.3.

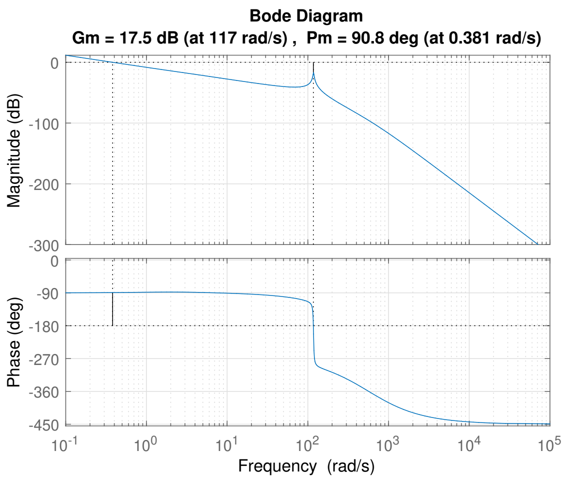


Figure 5.1: Bode plot for extension

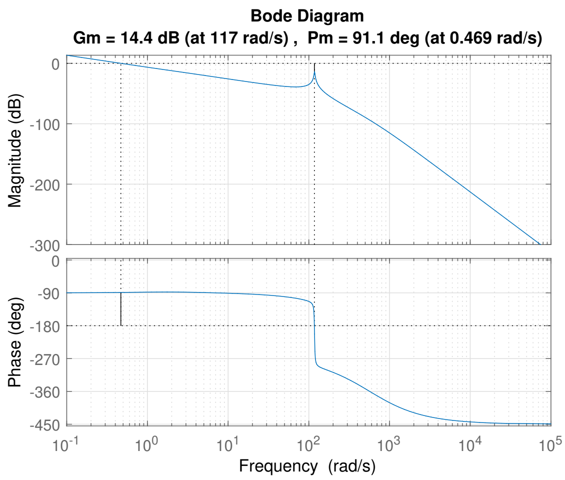


Figure 5.2: Bode plot for retraction

As seen on the figures both extension and retraction has a gain margin of 9.8dB with phase margin of 91°. The phase and gain margin both show that the system is stable. P-Controller implementation is shown theoretically in Subsection 5.1.1.

5.1.1 Theoretical P-Controller implementation

Matlabs built in step()-function was used to show the theoretical closed loop feedback for a simple P-controller, the feedback gain was estimated from the bode plot gain margins.

900 kg system

Theoretical response with P = 1 for extension and retraction in Figure 5.3 and P = 4 in Figure 5.4. The two figures shows that the theoretical system response even for a simple P-controller is improved drastically.

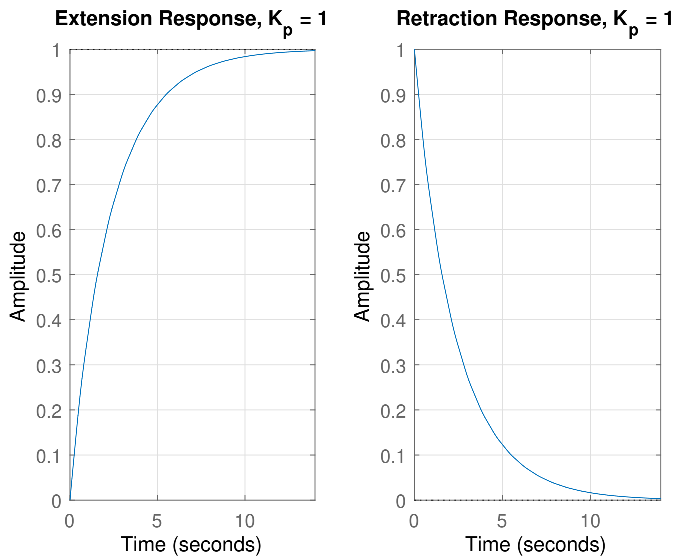


Figure 5.3: Theoretical response simple P-controller

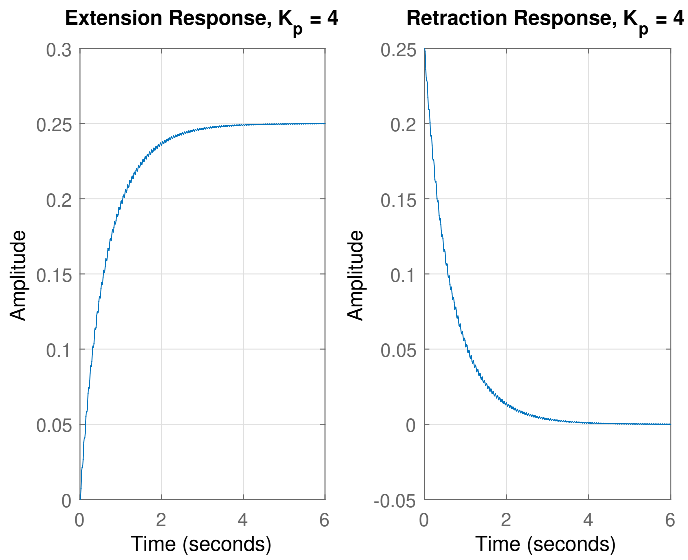


Figure 5.4: Improved theoretical response simple P-controller

5.1.2 Leakage Impact

The servo valve leakage is critical in order to obtain the required characteristic and the resulting pressure buildup. The effect of eliminating the leakage is shown on Figure 5.5 and 5.6 where the gain margin is observed to be reduced and the resulting step response for the same feedback gain is less stable.

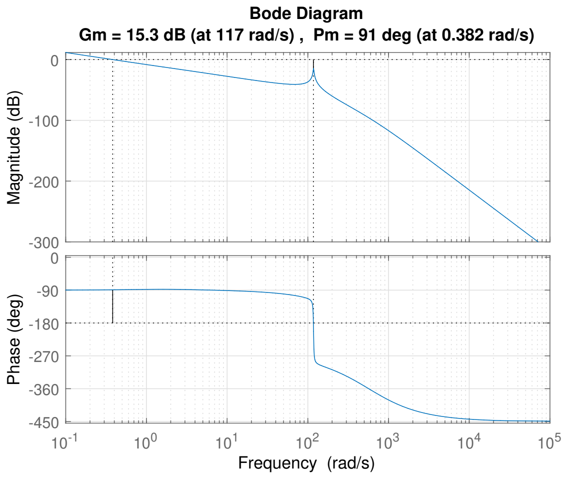


Figure 5.5: Bode plot for extension without leakage

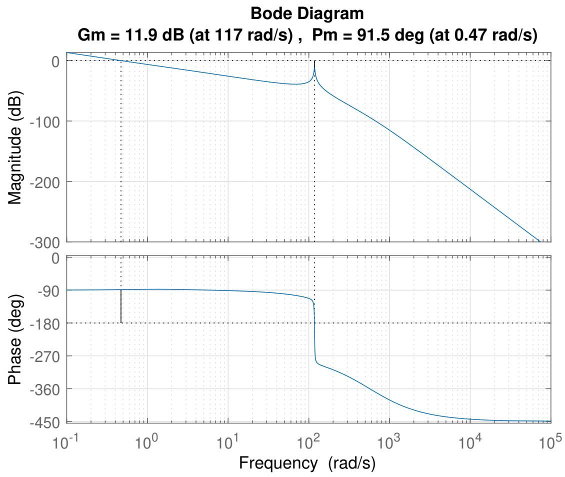


Figure 5.6: Bode plot for retraction without leakage

5.1.3 Stability for Increasing Loads

All bode plots previously are shown with effective mass of 900 kg. As there are interesting load scenarios the bode plots of these systems are shown in Figure 5.7 and 5.8 for respectively the extension and retraction for the 5 tonne effective inertia, Figure 5.9 and 5.10 for the 10 tonne effective inertia. From the bode diagrams it is observed that the gain margin has some reduction in load increase but due to the high system stiffness this reduction is marginal.

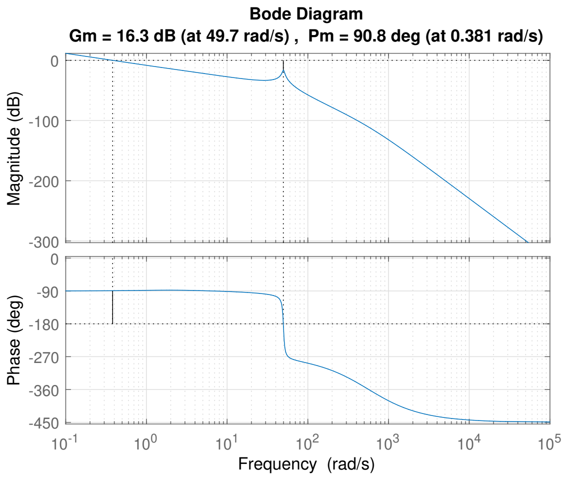


Figure 5.7: Bode plot for extension, 5 tonnes

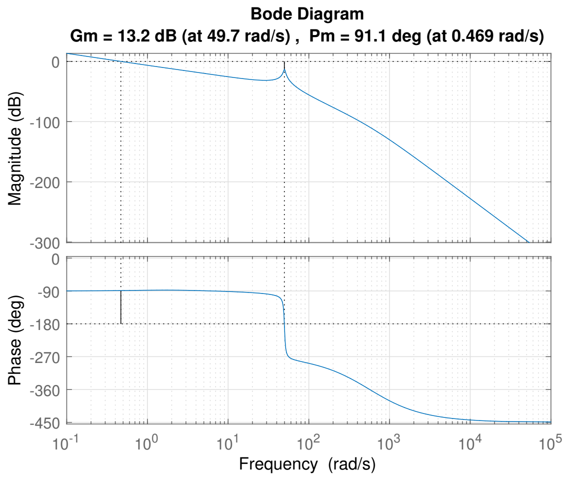


Figure 5.8: Bode plot for retraction, 5 tonnes

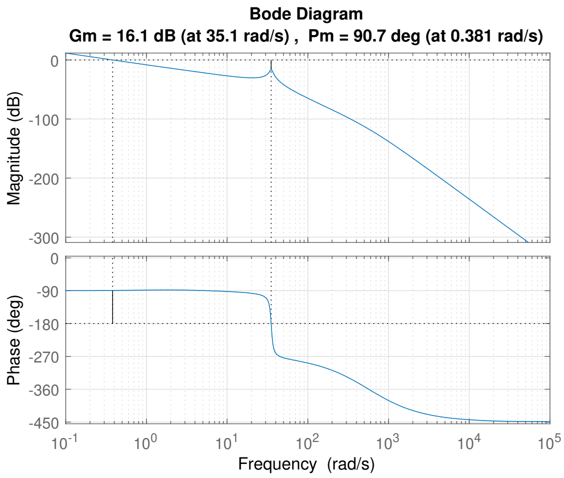


Figure 5.9: Bode plot for extension, 10 tonnes

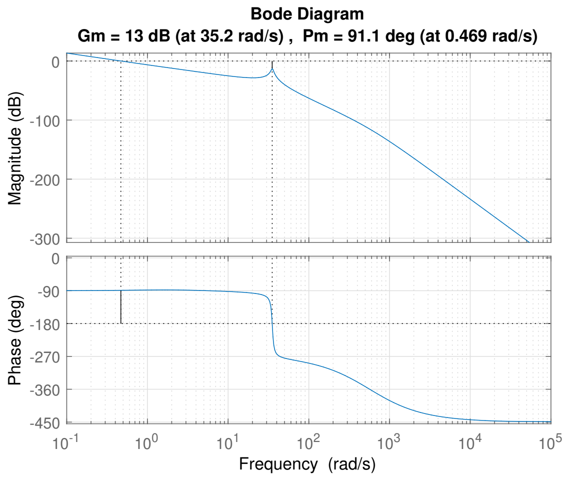


Figure 5.10: Bode plot for retraction, 10 tonnes

5.2 1-Pump Stability Margins, Increasing Loads

As mentioned in Subsection 5.1.3 the stability margins are marginally affected, even when increase of load with 9.9 tonne. For the pump system the expected bulk stiffness is expected to be lower and the resulting gain margin reducing with increasing load is significant. Figure 5.11 and 5.12 shows the stability margins for the effective load of 900kg system, Figure 5.13 and 5.14 shows the behavior when increasing the effective load to 5 tonne and increase to 10 tonne shown in Figure 5.15 and 5.16.

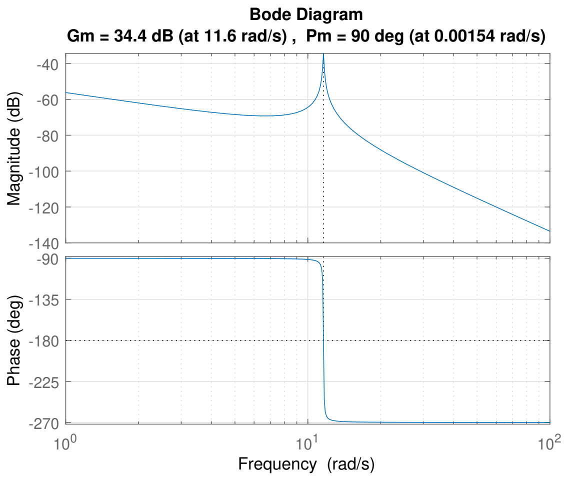


Figure 5.11: Extension stability margins, 900kg

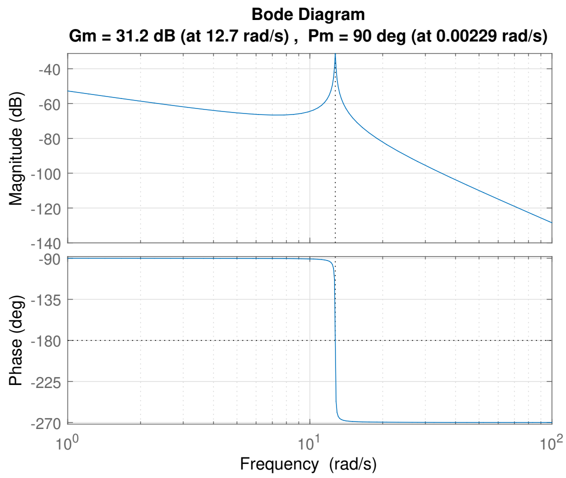


Figure 5.12: Retraction stability margins, 900kg

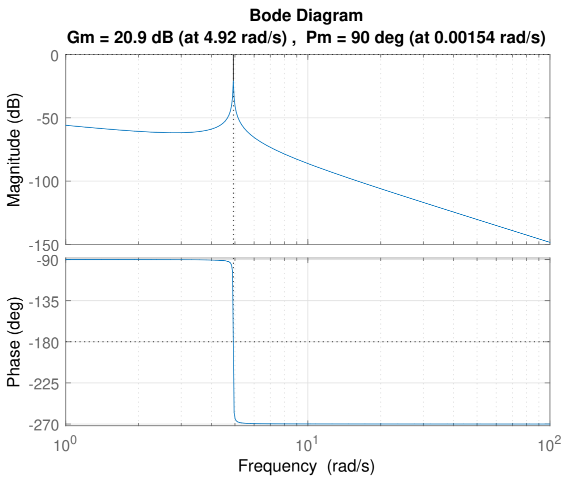


Figure 5.13: Extension stability margins, 5 tonne

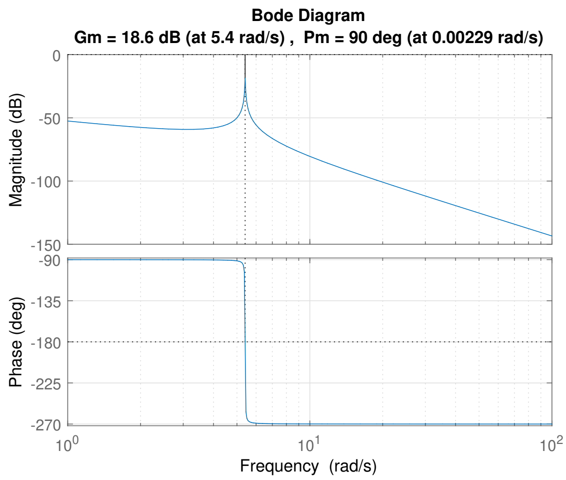


Figure 5.14: Retraction stability margins, 5 tonne

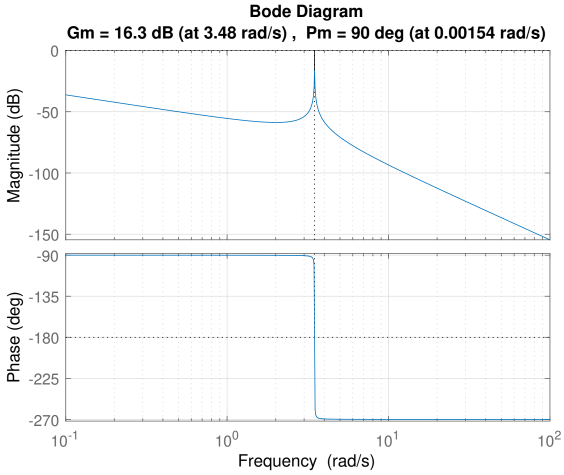


Figure 5.15: Extension stability margins, 10 tonne

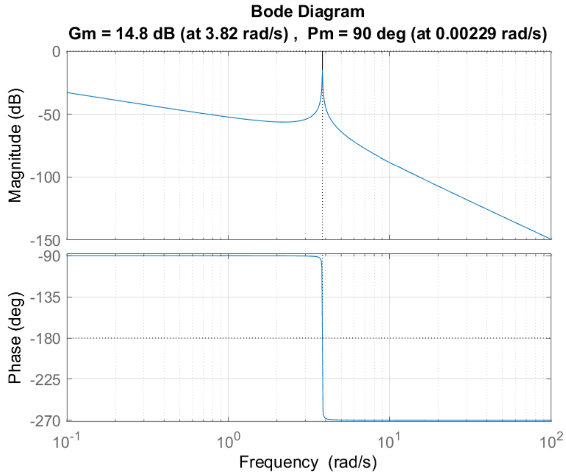


Figure 5.16: Retraction stability margins, 10 tonne

5.3 System Energy Use

5.3.1 Servo Valve Consumption

The power consumption of the valve system was estimated the the recorded max velocity of the platform during motion, in combination with Equation 5.1. The steady state pressures utilized in the servo valve linearization is assumed.

$$P_{hyd} = (p_{supply} - p_{bore}) \cdot Q_{in} + (p_{rod} - p_t) \cdot Q_{out} \tag{5.1}$$

5.3.2 2-Pump Consumption

The 2-pump consumption is measured for both motor and motor-controller to capture the entire energy consumption. A Hioko power analyzer was connected and configured for the corresponding 3-phase system with logging of rms current. The rms voltage was measured locally to 238.5V, energy consumption computed by Equation 5.2. The control power consumption was found to be around $50W$.

$$P = \sqrt{3} \cdot V_{rms} \cdot I_{rms} \tag{5.2}$$

Chapter 6

Experiment Design

6.1 Control Method

The control loops are constructed with the local motor directions, defined in Table 6.1.

Motor	Flow with positive velocity	Cylinder Movement
Primary Pump	Flow from B to A	Extension
Secondary Pump	Flow from A to *tank*	Retraction

Table 6.1: Pump flow and cylinder movement

Initially a simple P-controller for the motor control was implemented. This P-controller followed the simple loop in Equation 6.1, where the subscripts *prim* and *sec* denoted the primary and secondary motor. In the implemented PLC control method the output motor speed is limited to $\pm n_{max}$, this is omitted from the equations for notational clarity.

$$\begin{aligned} n_{motor,prim} &= K_{pos} \cdot (y - y_{ref}) \\ n_{motor,sec} &= -K_{pos} \cdot (y - y_{ref}) \cdot \alpha \end{aligned} \tag{6.1}$$

The α parameter exists to correct for the mismatch between pumps desired ration (A_2/A_1) and the pumps actual displacement ratio. Ideally the secondary pumps displacement would be found by Equation 6.2, however pumps are available within certain displacement settings and this is accounted for by finding the factor between ideal and actual displacement, α. Here α is found to be 0.8, i.e. secondary pump has greater than ideal displacement.

$$\frac{Q_{out}}{Q_{in}} = \frac{v \cdot A_2}{v \cdot A_1} = \frac{n \cdot (D_{prim} + D_{sec})}{n \cdot D_{prim}}$$
$$\Rightarrow D_{sec,ideal} = D_p \cdot (\frac{A_1}{A_2} - 1) \tag{6.2}$$

Figure 6.1 shows simulated system for step response and f 900kg effective load, $K_{pos} = 45$. 900kg corresponds to a test bed without load and is the simplest system to control.

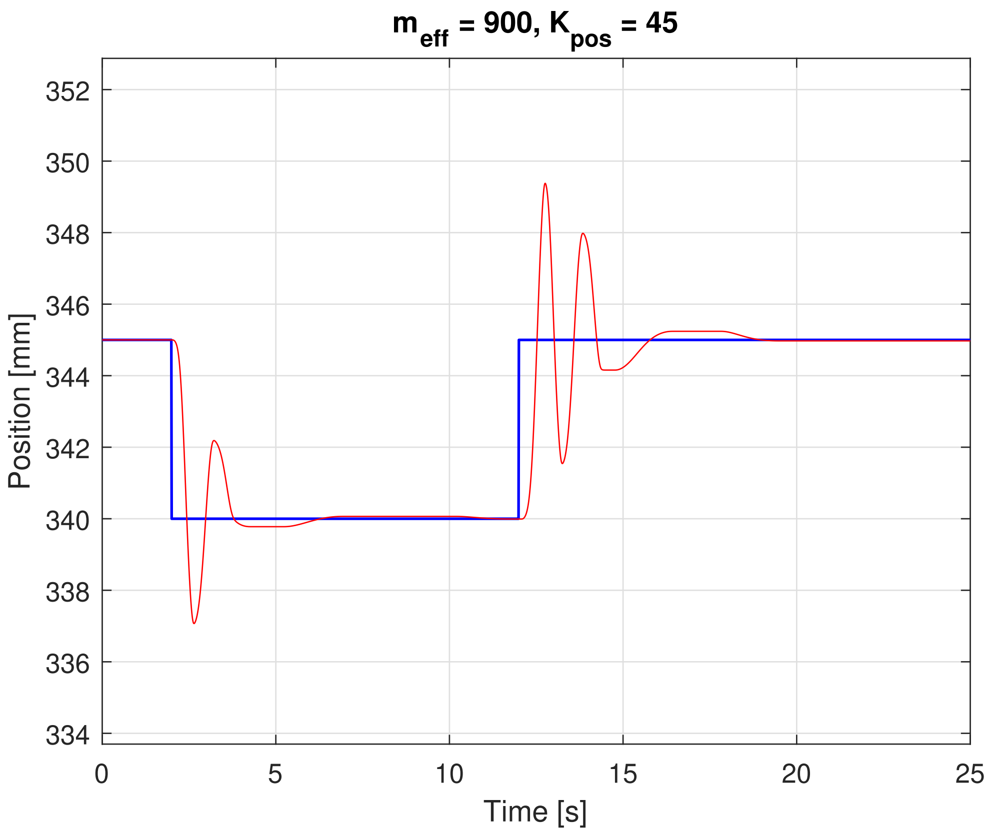


Figure 6.1: P-control example

From literature it has been reported that gas percentage as atmospheric pressure be as large as 20 %, from "Hydraulic Control Systems" [5]. With high percentage of gas present the resulting hydraulic stiffness is quite low and system performance is severely affected which is observed in Figure 6.2 where it can clearly be observed that the pressure buildup alternates to stop the system.

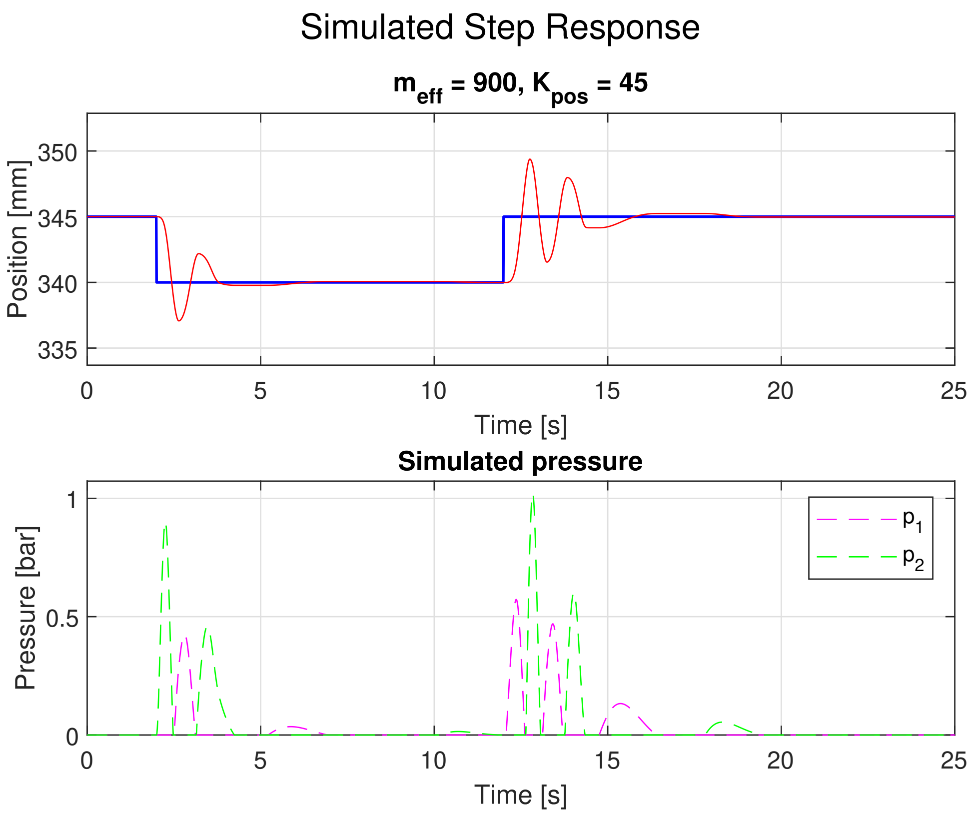


Figure 6.2: Figure 6.1 expanded

Increasing the system pressure is an effective method to increase the bulk modulus and additional steps was added to the control loop to ensure a certain pressure present in the system. The control loop is set up to move oil from "bore->rod **AND** tank->bore " when the pressure in the system is lower than desired, and opposite if sum of pressure is greater than desired. The β factor ensured was adjusted by trial and error on which value provided the best system response. The

$$\begin{aligned} n_{motor,prim} &= K_{pressure} \cdot (p_{sum} - (p_1 + p_2)) \\ n_{motor,sec} &= -K_{pressure} \cdot (p_{sum} - (p_1 + p_2)) \cdot \beta \end{aligned} \tag{6.3}$$

Simulating the system with a simple $p_{sum} = 2$ and $K_{pressure} = 500$ shows that the step response is drastically improved with the addition to the control algorithm 6.3.

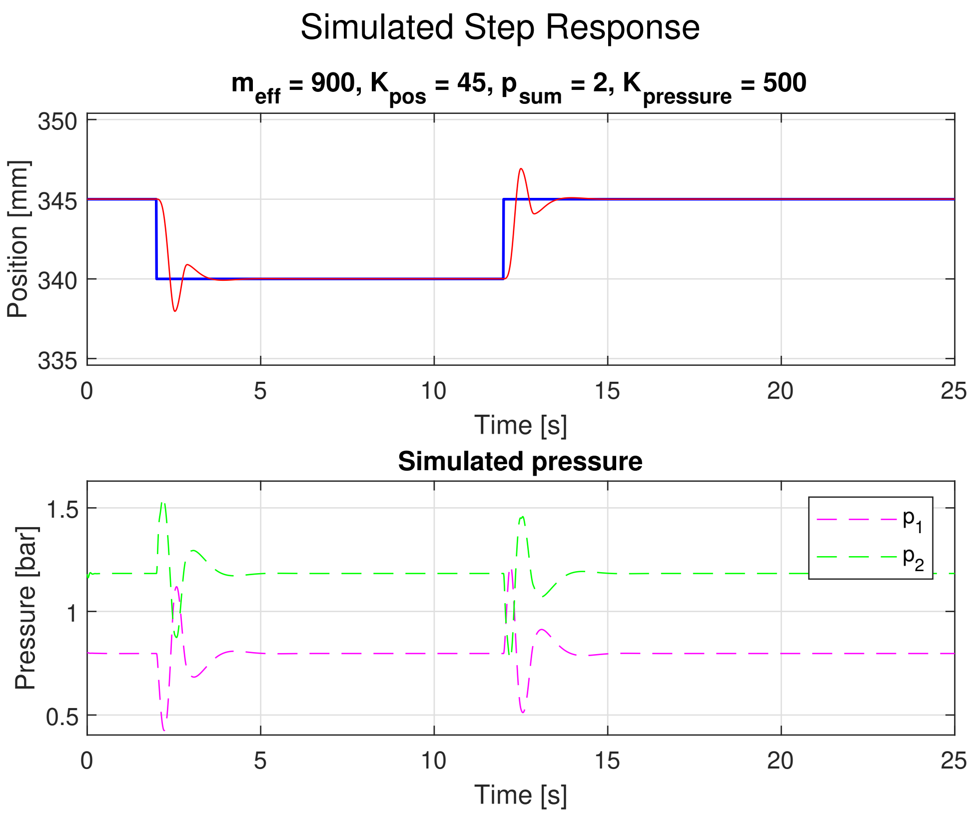


Figure 6.3: Pressure control example

Acceleration feedback was tested to observe the dampening effect such controller can deliver. The acceleration feedback, Equation 6.4, was implemented and with the same step response it can be seen in Figure 6.4 that oscillations are damped.

$$\begin{aligned} n_{motor,prim} &= (p_1 \cdot A_1 - p_2 \cdot A_2) \cdot \frac{K_{acc}}{m_{eff}} \\ n_{motor,sec} &= -(p_1 \cdot A_1 - p_2 \cdot A_2) \cdot \frac{K_{acc}}{m_{eff}} \end{aligned} \tag{6.4}$$

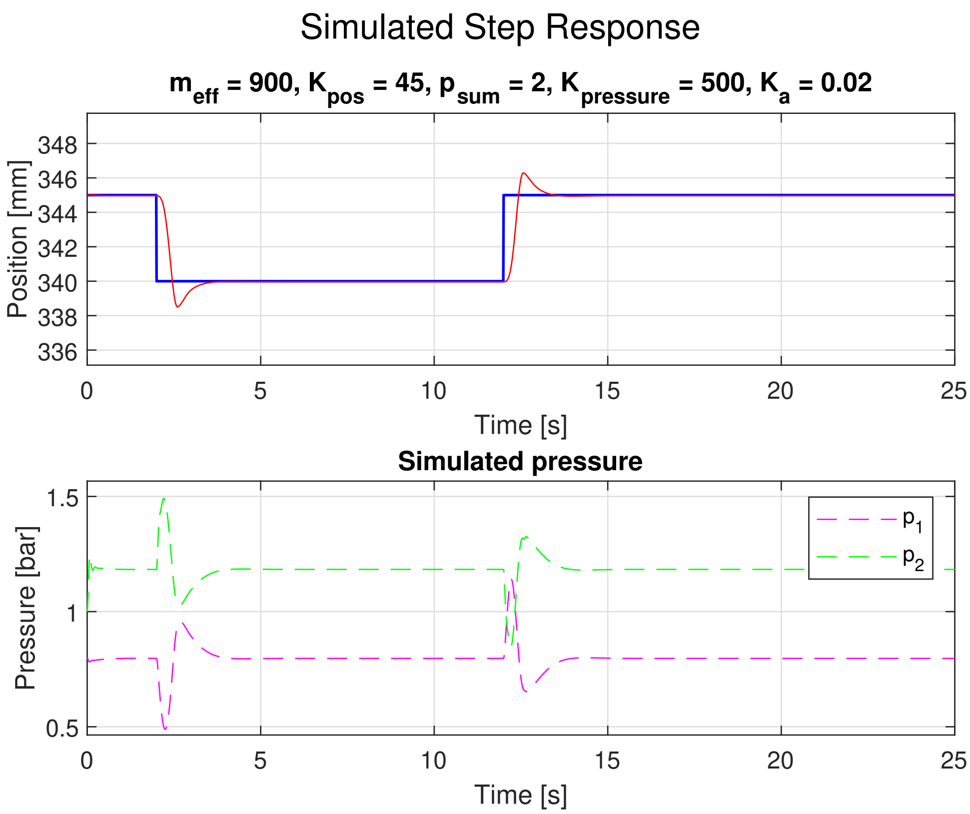


Figure 6.4: Acceleration control example

The final control law is repeated in Equation 6.5

$$
\begin{aligned}
n_{motor,prim} &= K_{pos} \cdot (y - y_{ref}) + K_{pressure} \cdot (p_{sum} - (p_1 + p_2)) + (p_1 \cdot A_1 - p_2 \cdot A_2) \cdot \frac{K_{acc}}{m_{eff}} \\
n_{motor,sec} &= -K_{pos} \cdot (y - y_{ref}) \cdot \alpha - K_{pressure} \cdot (p_{sum} - (p_1 + p_2)) \cdot \beta - (p_1 \cdot A_1 - p_2 \cdot A_2) \cdot \frac{K_{acc}}{m_{eff}}
\end{aligned}
\tag{6.5}
$$

6.2 PLC Setup

The Beckhoff PLC was utilized for reading sensors, implementing control logic, data logging and the creation of a HMI. The beckhoff PLC main task was configured to execute every 10ms and set to call every other program from the main task using the call-logic demonstrated in Figure 6.5. PLC software developed using TwinCAT 3 Engineering and was programmed using Structured text, a language designed for PLCs. On Beckhoff PLC the structured text language may be used to call function blocks [9].

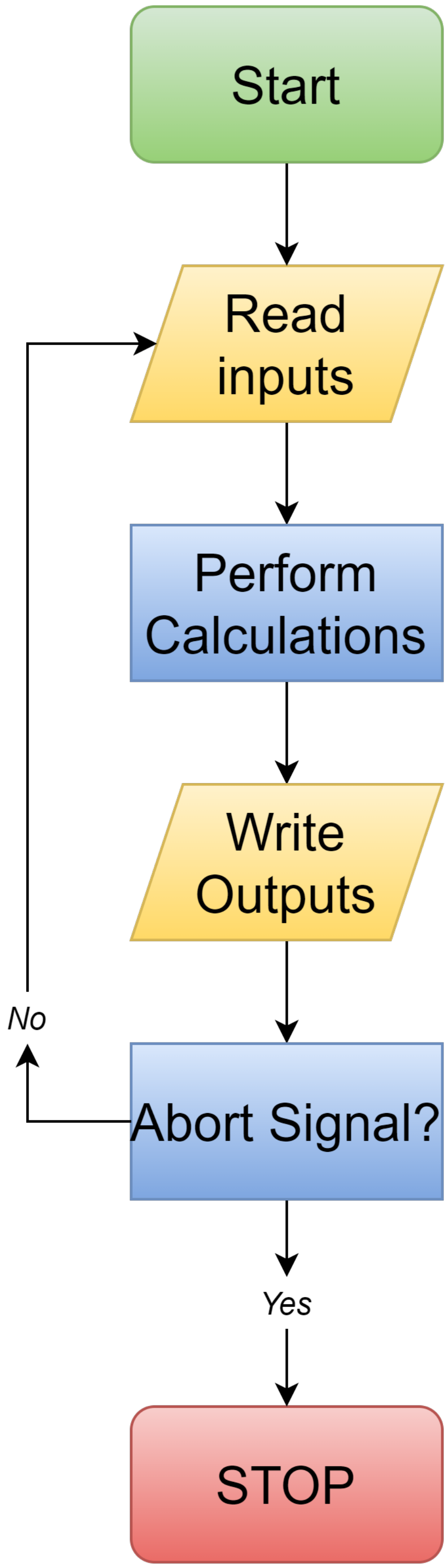


Figure 6.5: PLC Flowchart

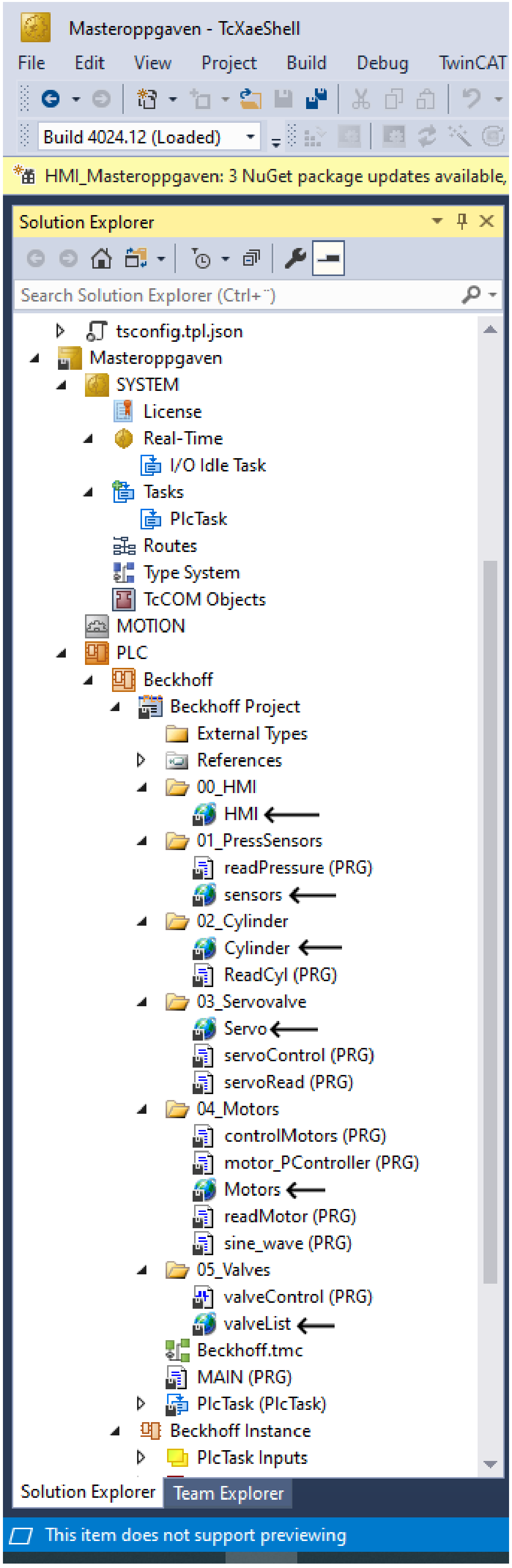


Figure 6.6: PLC file organization

The PLC program structure was set up as seen in Figure 6.6 where each folder is dedicated to a specific system part where variable list (marked with arrows) and programs (ends with PRG) for that specific system part. Local variables are only contained to programs where used with the variable list being global and accessible for the system.

6.2.1 Data Logging and Real Time Graphing

Real time graphing of data was implemented such that every sensor value could be observed if desired. The total graphing was divided into 3 time-graphs, a graph with cylinder reference and value, a graph with system pressure and a graph with the control values for the motors. Example of system graphs can be observed in Figure 6.7 where cylinder position, cylinder setpoint and system pressure are shown simultaneous.

The data logging is configured to allow for saving of the graphed data once the real time graphing has been stopped. The data logging and graphing are both running on the Beckhoff PLC to ensure that the data is logged with known $100Hz$ sampling frequency. The graphs only updated once per second.

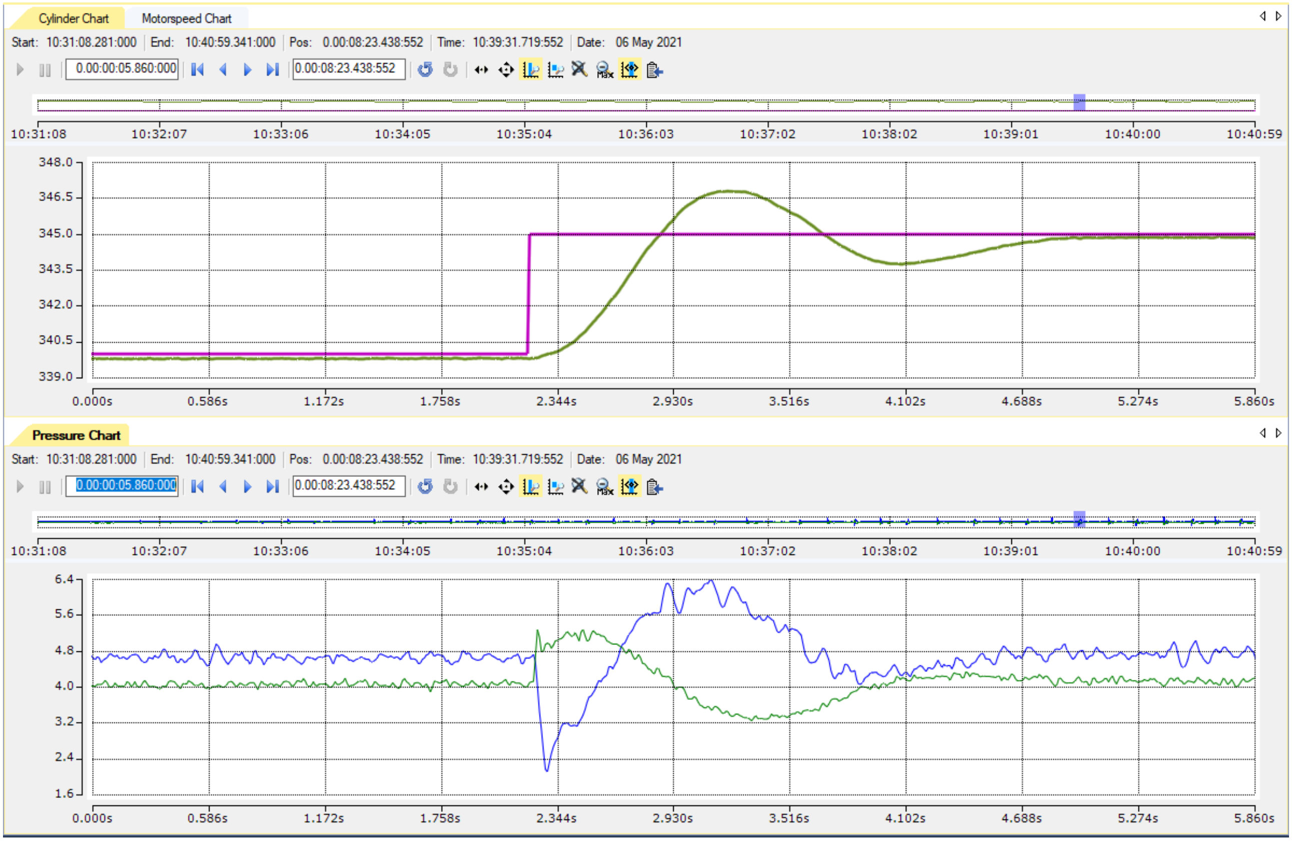


Figure 6.7: Cylinder chart and Pressure chart shown

6.2.2 Pressure Signal Precision

In the system there are multiple analogue pressure sensors. In the PLC each sensor signal was configured to be stored as an integer with 2 decimal precision, by scaling the signal 2 decades greater than the actual required scaling. This was possible by utilizing sufficient data types to avoid overflow for the scaled value.

6.2.3 Cylinder Sensor Precision

The cylinder sensor is an LVDT with both position and velocity output. The cylinder positioning implemented as an integer with up to 3 decimals or 0.01 mm accuracy and the velocity implemented as an integer with 1 decimal precision or 0.1 mm/s. The specific integer data type was ensured to be sufficient for the variables.

6.2.4 HMI

As part of creating a implementing system control a HMI was setup using the Twincat HMI module. The designed HMI, shown in Figure 6.8, was setup in such a way that the first the mode is selected, as highlighted in Figure 6.9, and depending on selected mode different areas of the control panel is utilized. This was done as to have the controls for each mode in close proximity, each mode with their own set of buttons for full use of each modes functionality. The default mode, everything off, sets every output to its off value.

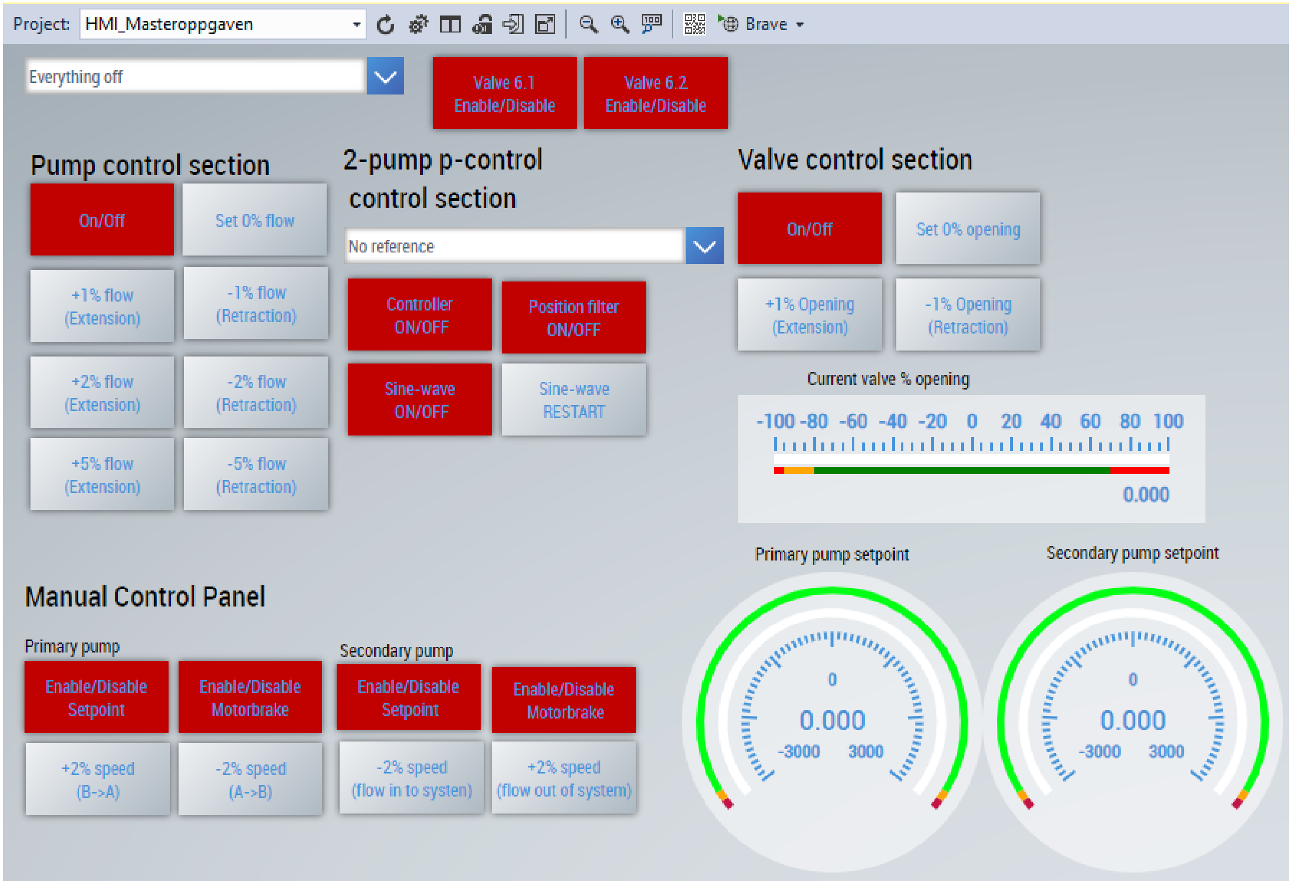


Figure 6.8: Full HMI view

The primary and secondary motor-pump reference speeds are displayed, used to keep track of speed and direction in manual operation mode. Examples of P-Controller mode selection in Figure 6.10. Buttons with on/off state are respectively green/red to reflect their state.

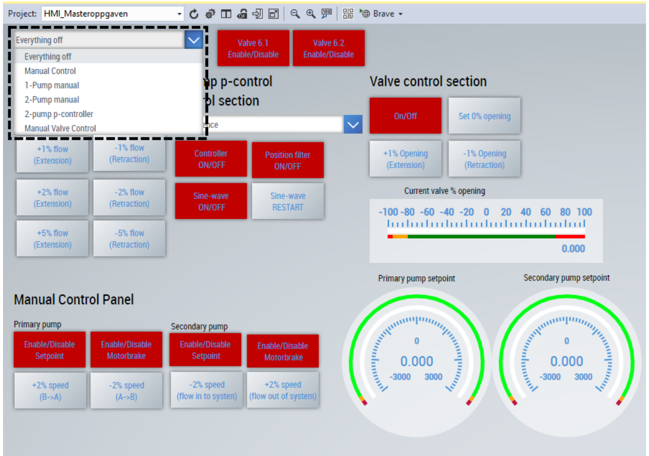


Figure 6.9: Mode selection

Figure 6.10: P-Controller reference selection

6.2.5 Noise Filtering

As mentioned in 3.3.5 the electrical layout was such that sensitive analogue signals was routed away from the PSU. By utilizing smart cable routing and properly grounded cable shield the resulting instrument noise was non-significant and signals could be implemented directly. Figure 6.11 shows the typical cylinder noise of ± 0.15 mm with Figure 6.12 showing the ± 0.15 bar noise.

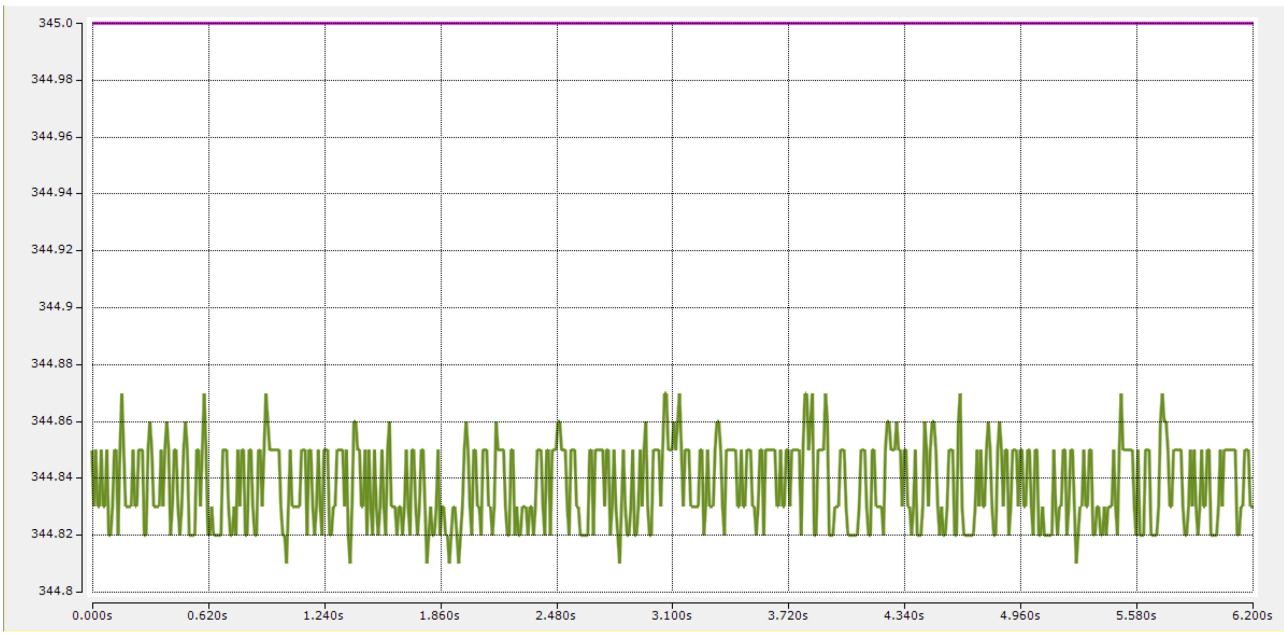


Figure 6.11: Cylinder Noise

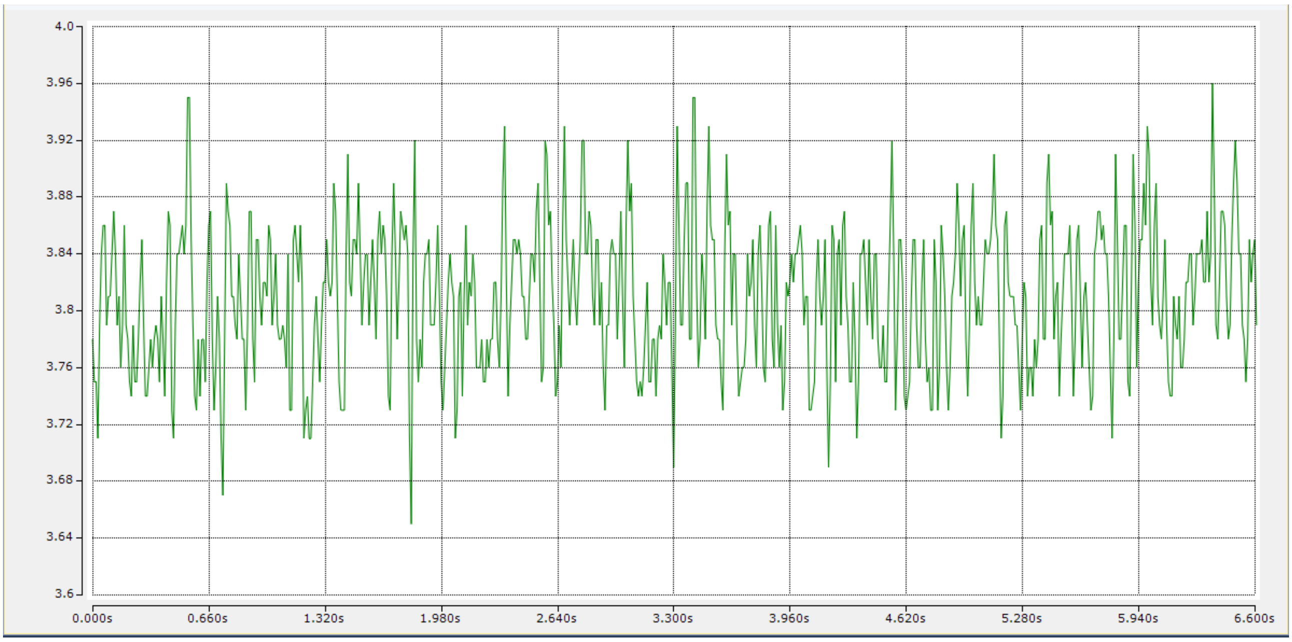


Figure 6.12: Pressure Noise

6.3 System Emergency Stops

Multiple emergency levels was designed for full control and operator safety. The first level is that of the ON/OFF buttons in the HMI, with additional level of safety stops with physical switches for motor brakes, enabling/disabling of motor controller and an emergency button that cuts the supply power to the motor controllers.

The emergency button, motor brake switches and enable/disable switches are all setup on control panel with roughly $2m$ of extra wire such that the physical buttons are not fixed in location and quite flexible.

Chapter 7

Results

This chapter shows data from the real system for multiple loads, the simulated system response for the same loads and the system energy efficiency and consumption.

7.1 Real Results

In this section the results from the real system are considered. Table 7.1 repeats the angles and corresponding cylinder values.

Desired angle	Corresponding cylinder movement
2	20 mm
4	35 mm
5	50 mm

Table 7.1: Angle - cylinder movement table

7.1.1 2-Pump Circuit 5 Tonnes Effective Inertia

All tests use $K_{pressure}$ equal to 1200 with P_{sum} set to 10 bar and K_{acc} equal to 0.00 . Additionally the wave compensation has K_p set to 40 for all wave motions.

Step Response

The step response for $K_p = 25$, shown in Figure 7.1, has a steady state error of 0.1 mm and 4.0% overshoot

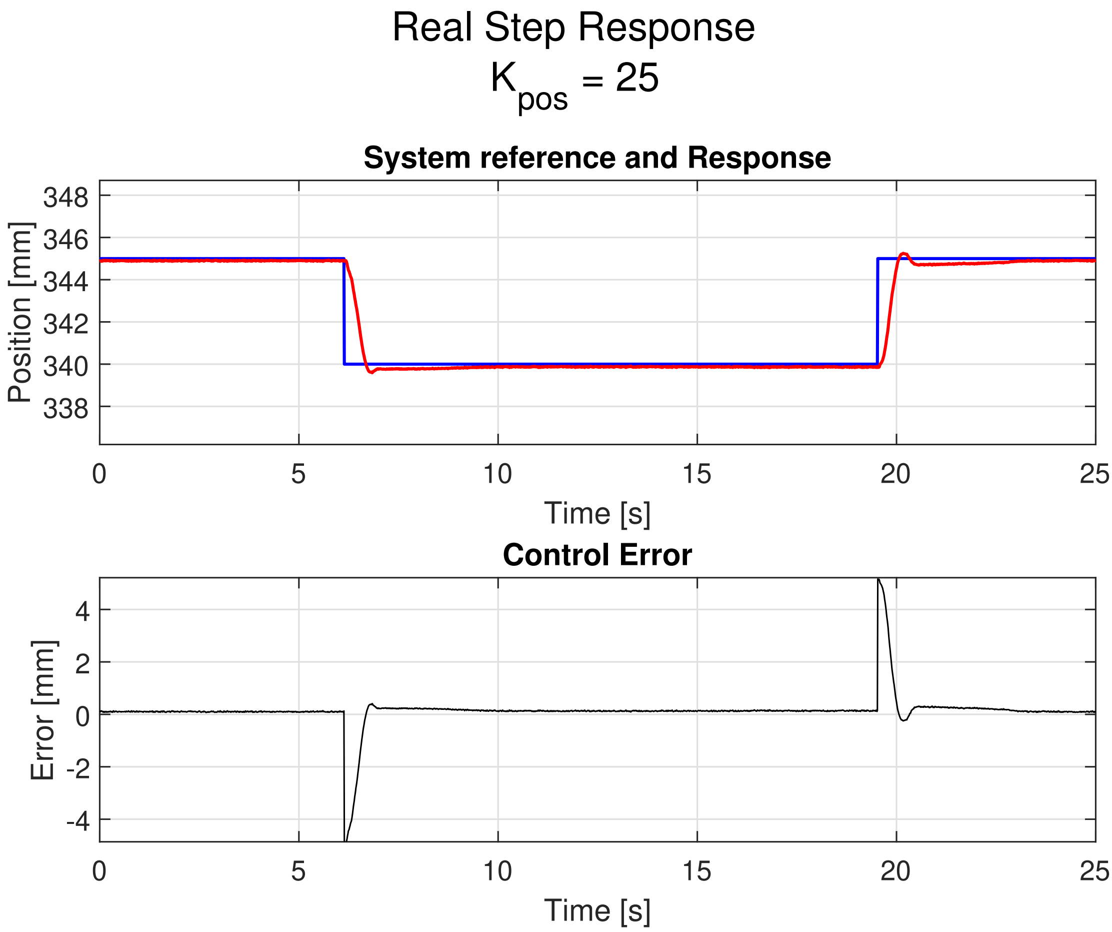


Figure 7.1: Step response 2-pump system with $K_p = 25$

The step response with $K_p = 40$, shown in Figure 7.2, has a steady state error of 0.07 mm and 44% overshoot.

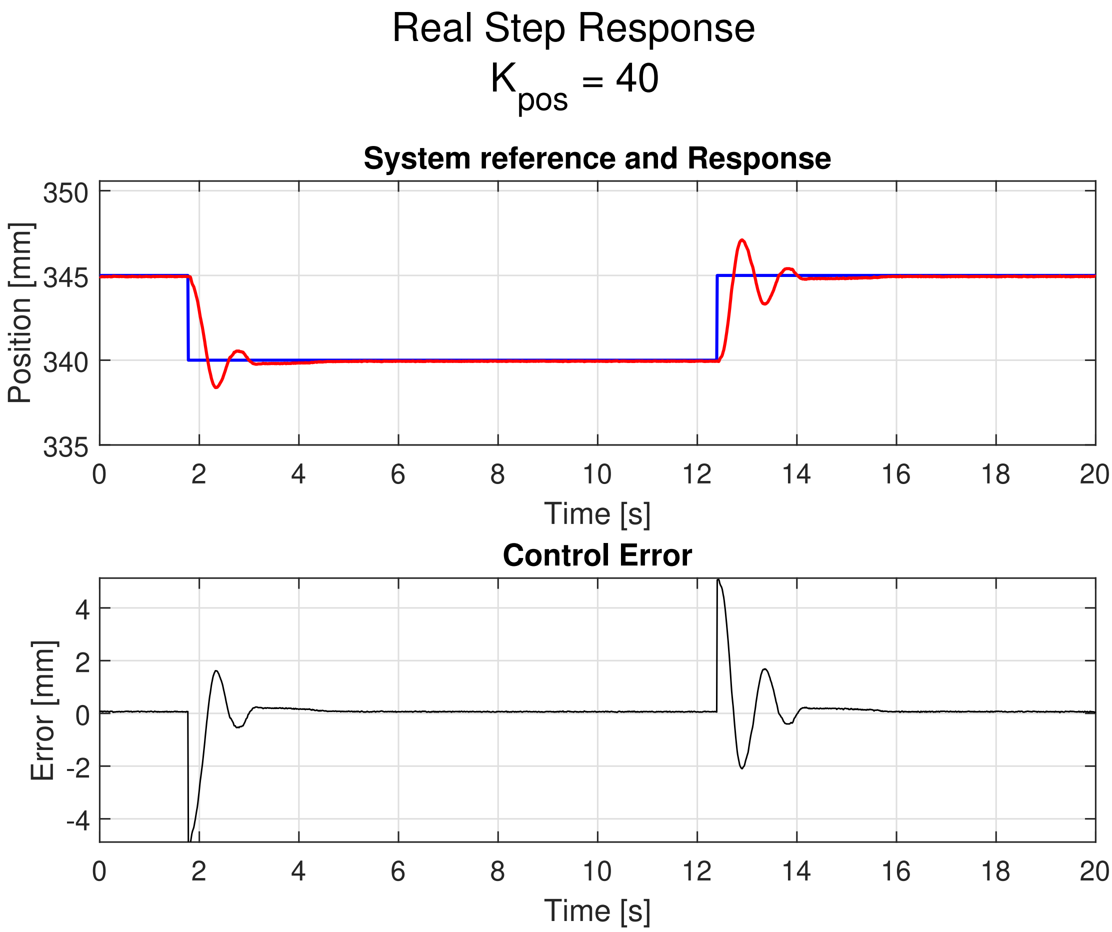


Figure 7.2: Step response 2-pump system, $K_p = 40$

The step response with $K_p = 50$, shown in Figure 7.3, has a steady state error of 0.15 mm and 52% overshoot.

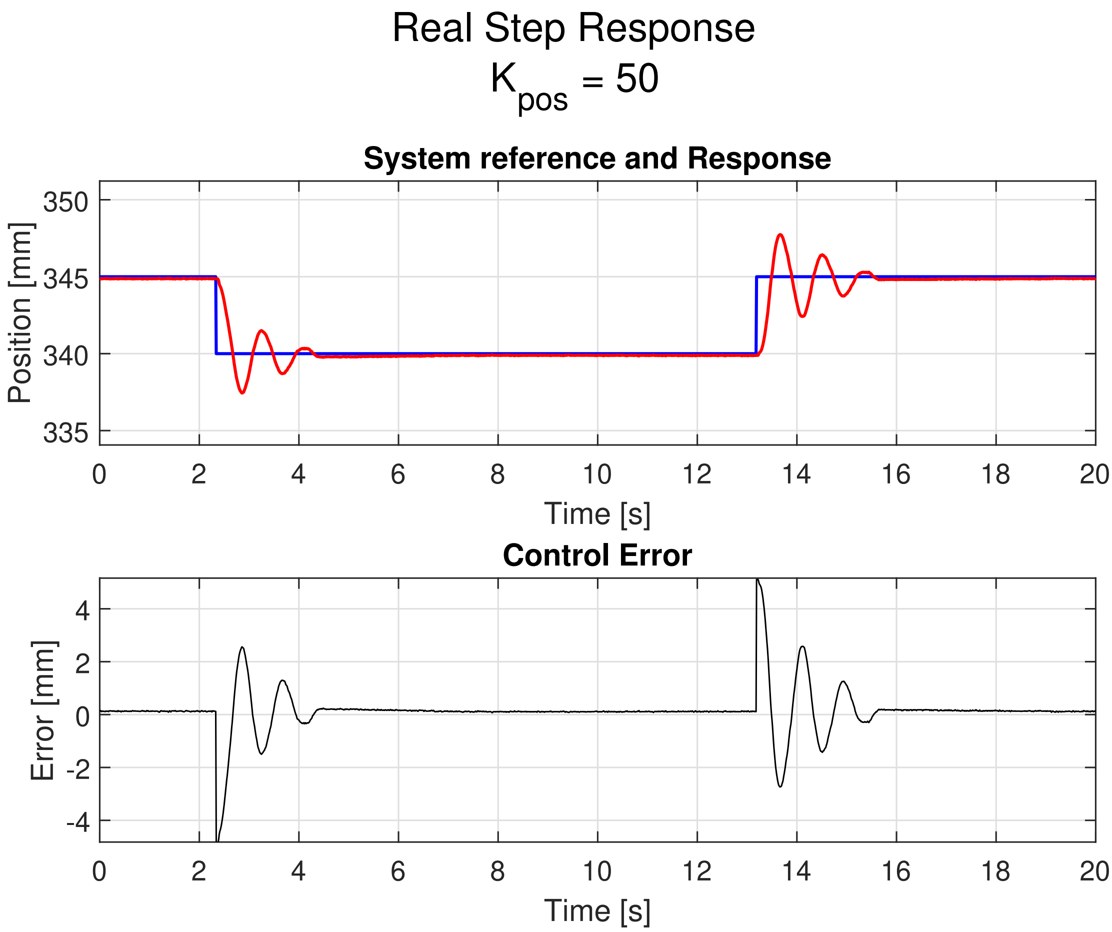


Figure 7.3: Step response 2-pump system, $K_p = 50$

20mm 0.1Hz Sine-wave

Maximum error for stable oscillations of 2.6 *mm* meaning 87% wave compensation. Wave motion of 2.0° reduced to 0.26°. Figure 7.4 shows wave and control error.

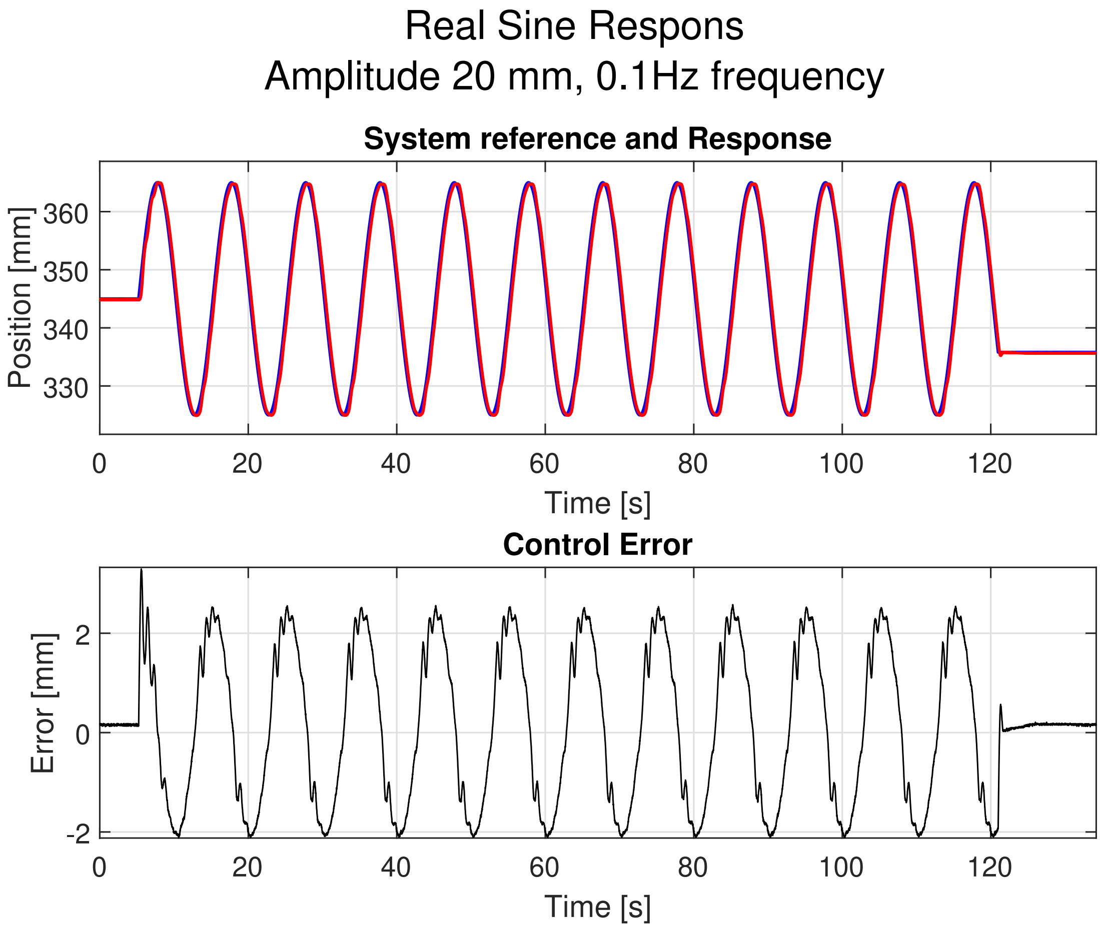


Figure 7.4: Sinusoidal motion, reference and error #1

35mm 0.1Hz Sine-wave

Maximum error for stable oscillations of 4.2 mm meaning 83% wave compensation. Wave motion of 4.0° reduced to 0.48°. Figure 7.5 shows wave and control error.

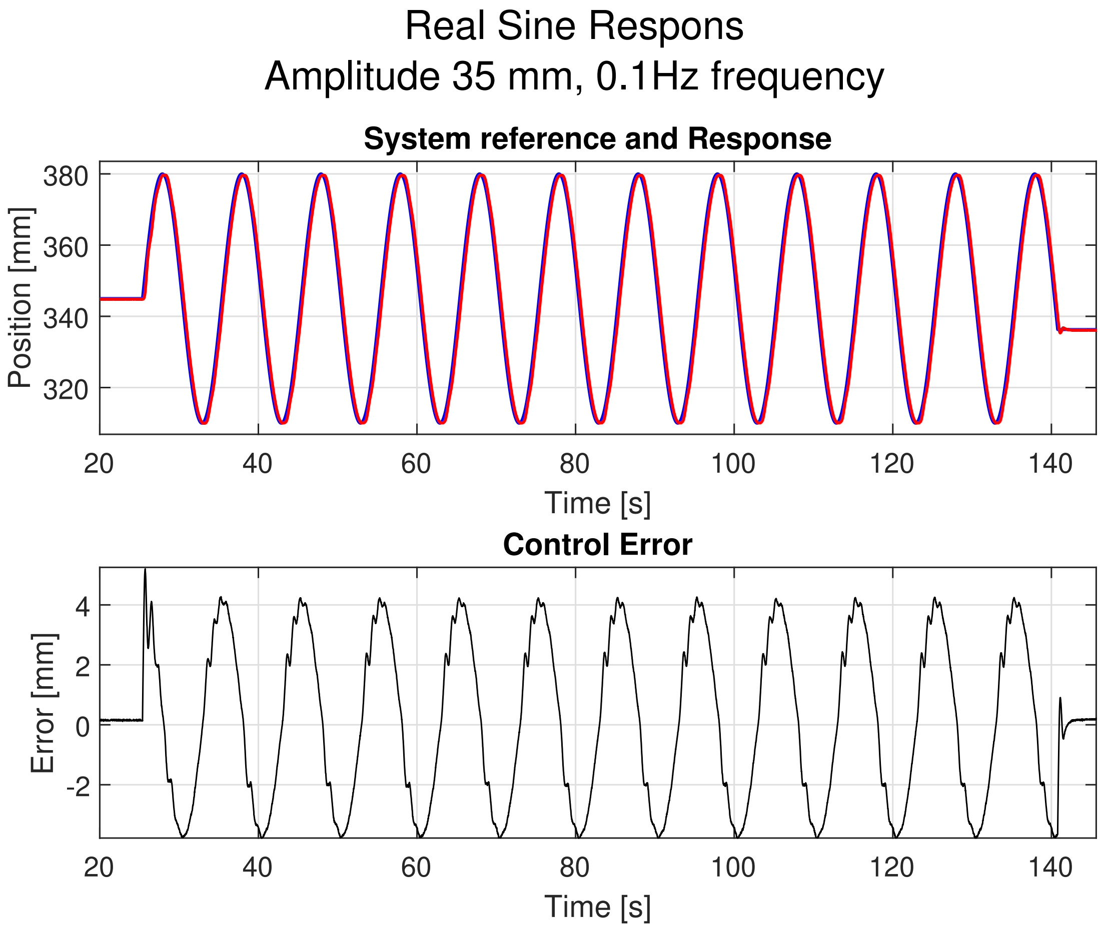


Figure 7.5: Sinusoidal motion, reference and error #2

50mm 0.1Hz Sine-wave

Maximum error for stable oscillations of 5.9 *mm* meaning 88% wave compensation. Wave motion of 5.0° reduced to 0.60°. Figure 7.6 shows wave and control error.

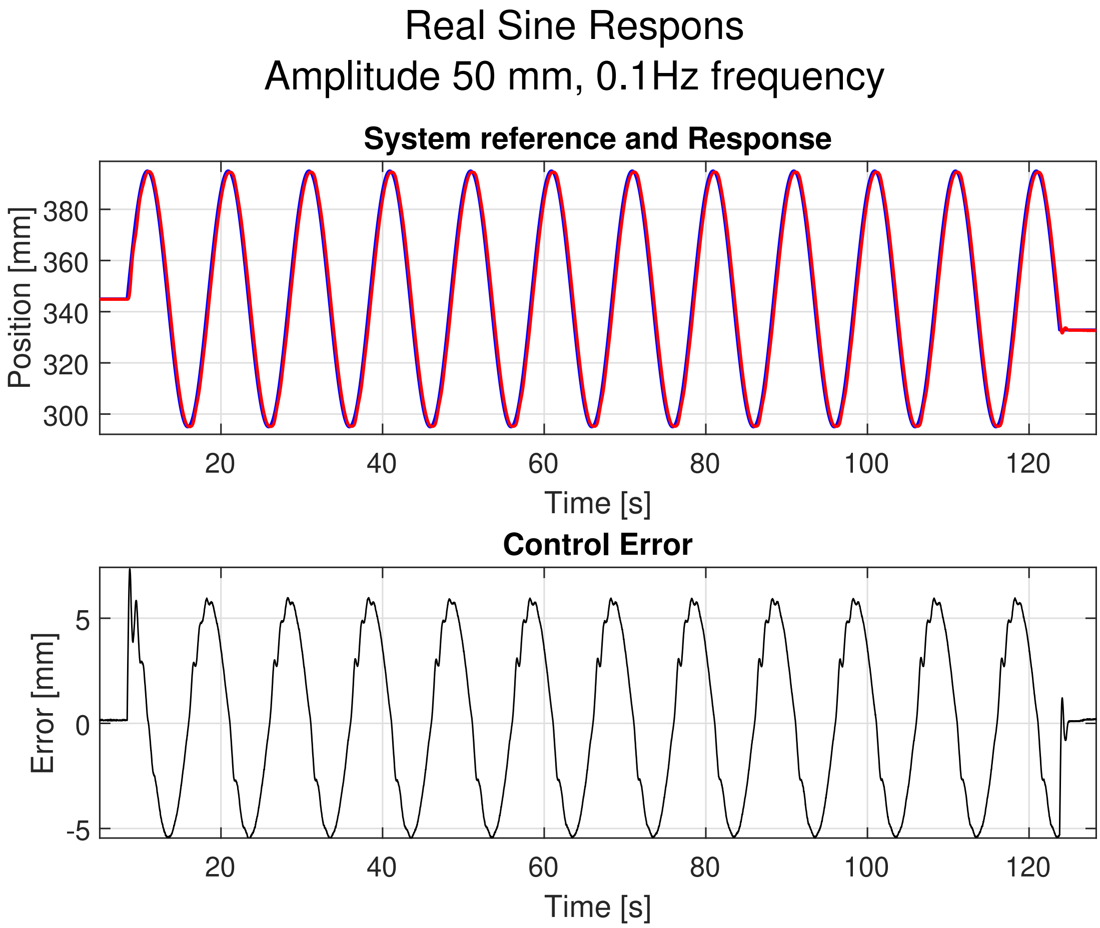


Figure 7.6: Sinusoidal motion, reference and error #3

20mm 0.2Hz Sine-wave

Maximum error for stable oscillations of 4.9 *mm* meaning 76% wave compensation. Wave motion of 2.0° reduced to 0.5x°. Figure 7.7 shows wave and control error.

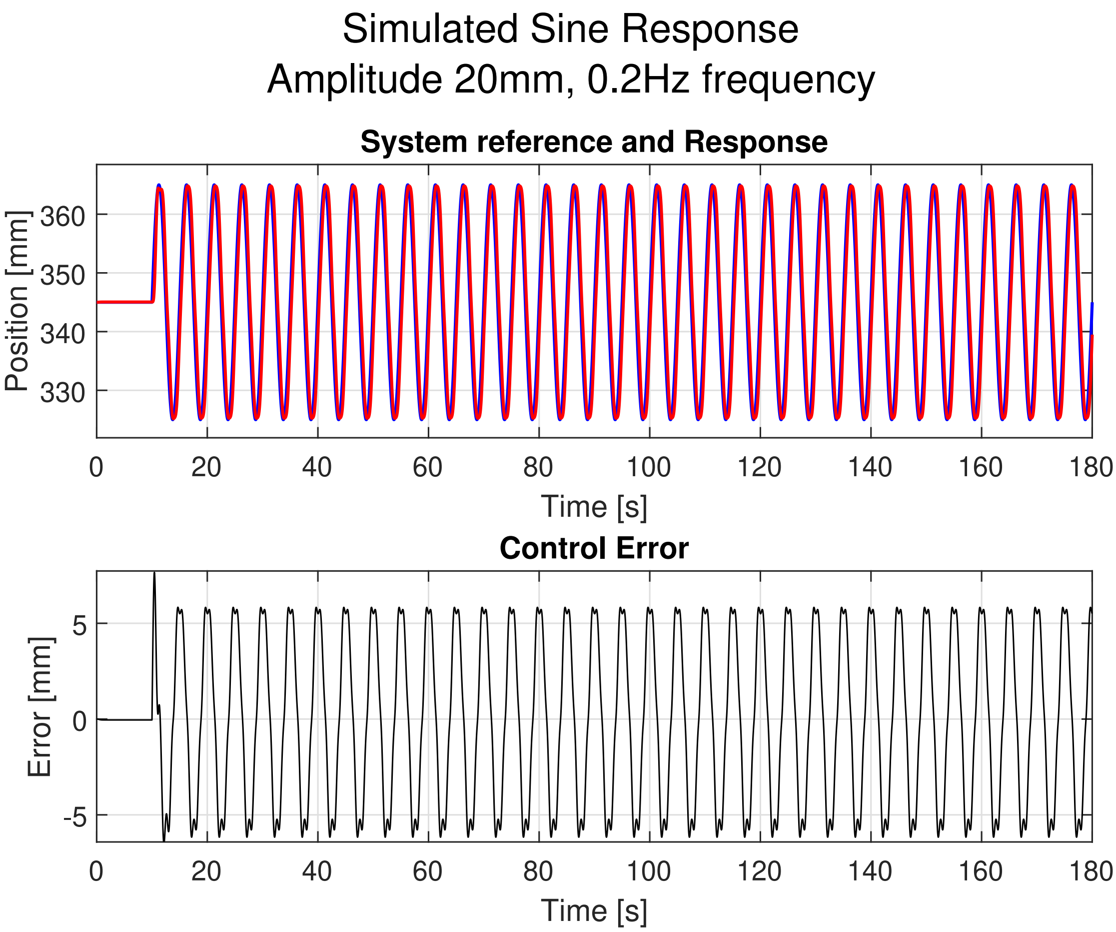


Figure 7.7: Sinusoidal motion, reference and error #4

35mm 0.2Hz Sine-wave

Maximum error for stable oscillations of 8.3 *mm* meaning 76% wave compensation. Wave motion of 4.0° reduced to 0.96°. Figure 7.8 shows wave and control error.

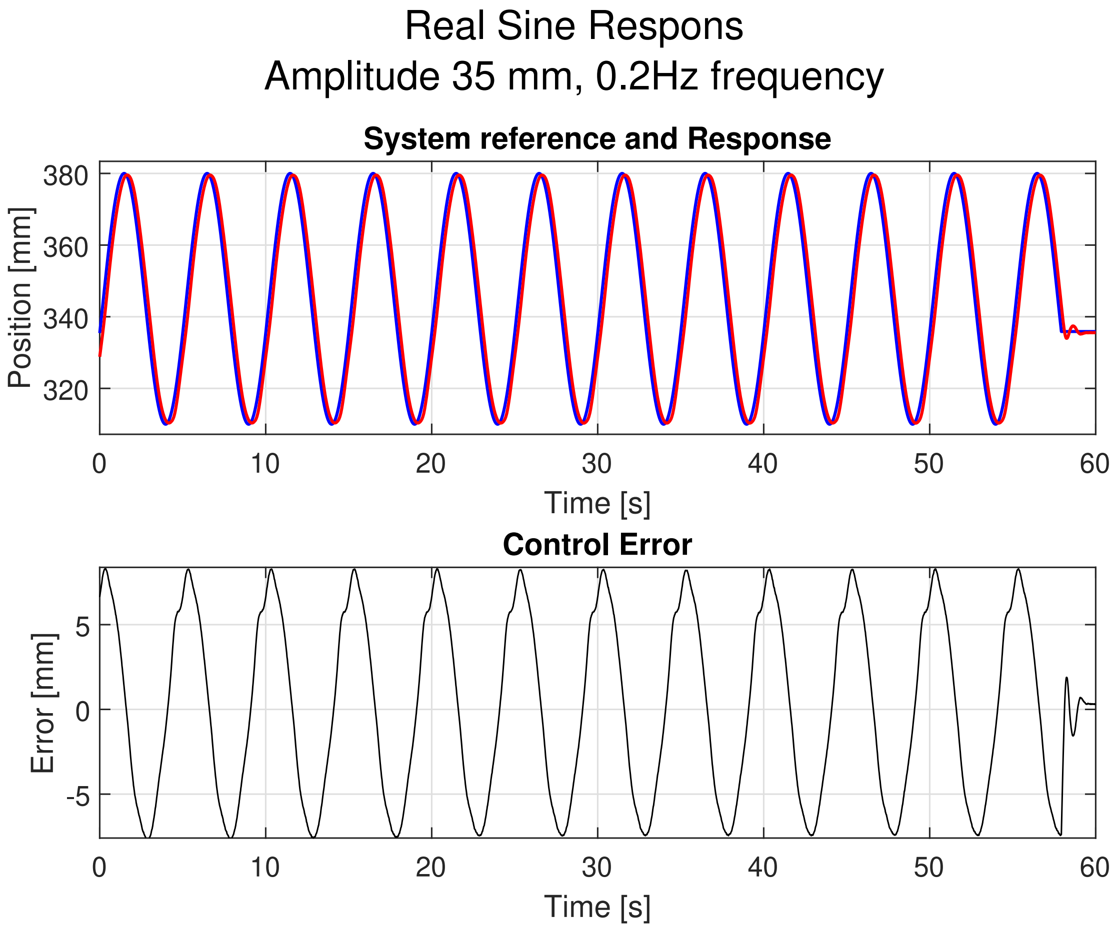


Figure 7.8: Sinusoidal motion, reference and error #5

20mm 0.25Hz Sine-wave

Maximum error for stable oscillations of 5.6 mm meaning 72% wave compensation. Wave motion of 2.0° reduced to 0.56°. Figure 7.9 shows wave and control error.

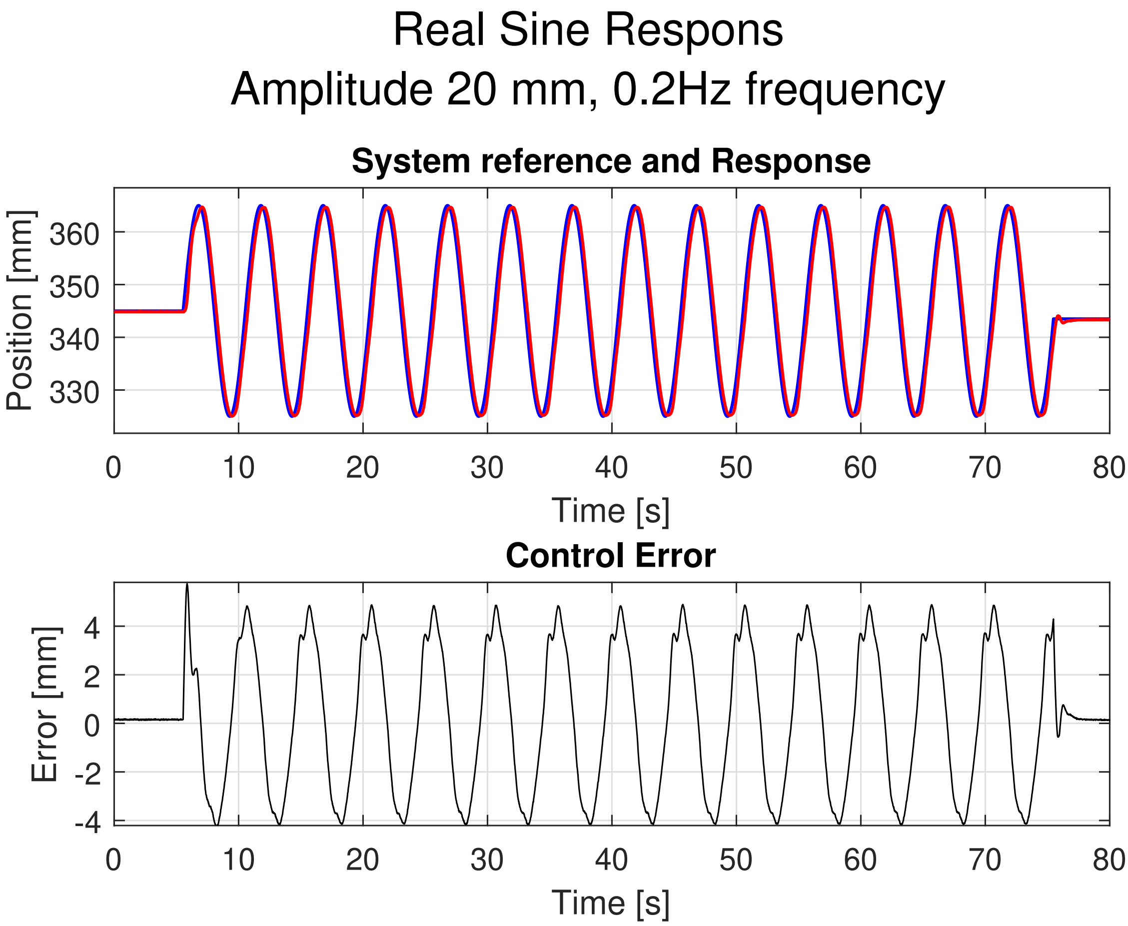


Figure 7.9: Sinusoidal motion, reference and error #6

7.1.2 2-Pump Circuit 10 Tonnes Effective Inertia

All graphs shows $K_{pressure}$ equal to 1200 with p_{sum} set to 10 bar. All wave compensation tests use K_p of 25.

Step Response

The step response for $K_p = 20$ shown in Figure 7.10 with an steady state error of 0.06 mm with 28% OS.

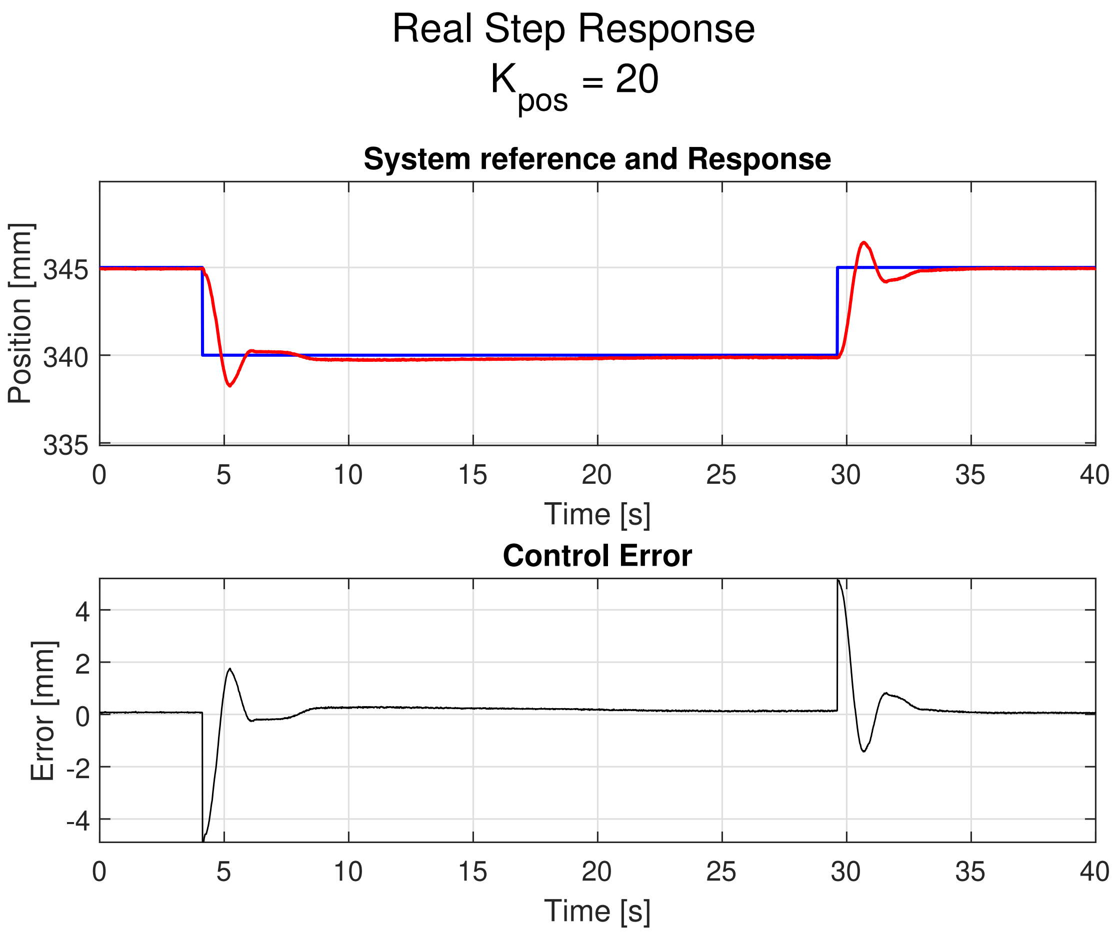


Figure 7.10: Step response 2-pump system, $K_p = 20$

The step response for $K_p = 25$ shown in Figure 7.11 with an steady state error of 0.18 mm with 42% OS.

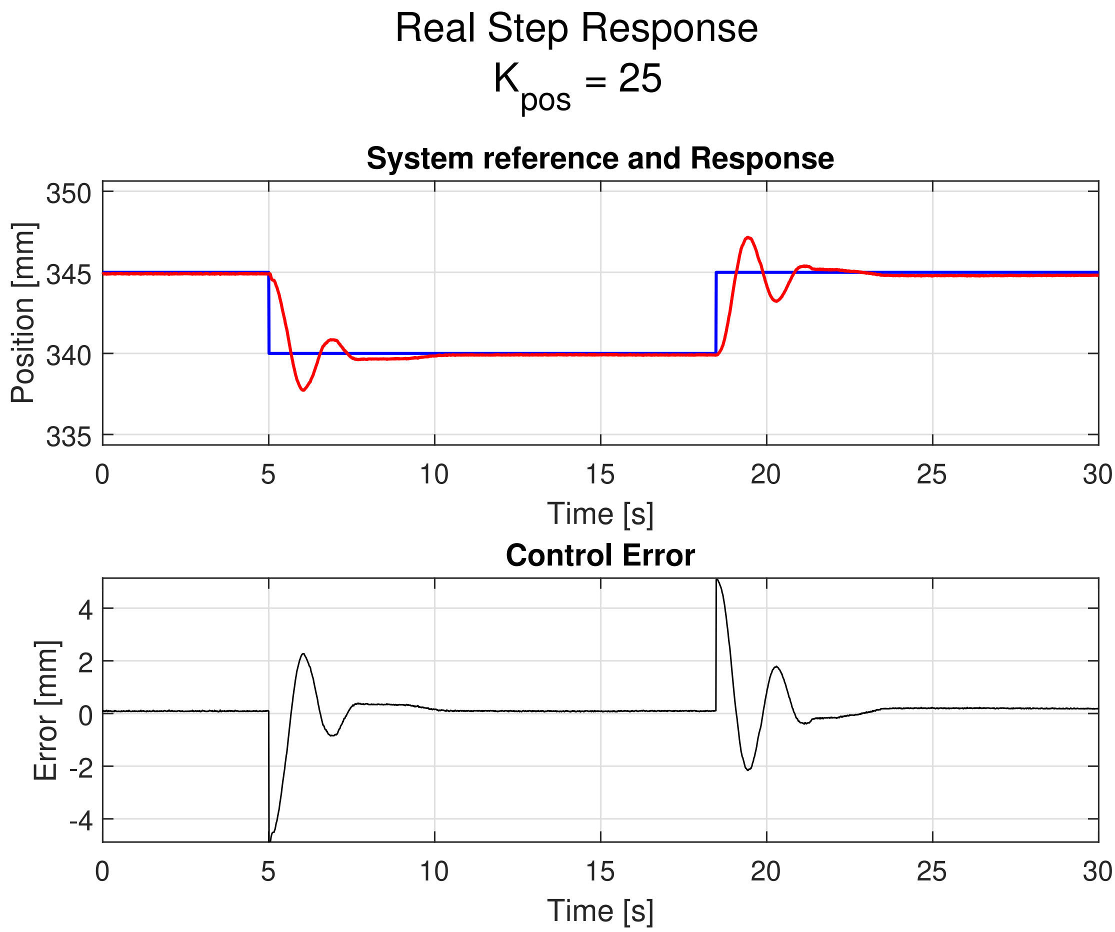


Figure 7.11: Step response 2-pump system, $K_p = 25$

20mm 0.1Hz Sine-wave

Maximum error of 4.2 mm meaning 80% wave compensation. Wave motion of 2.0° reduced to 0.4°. Figure 7.12 shows motion and control error.

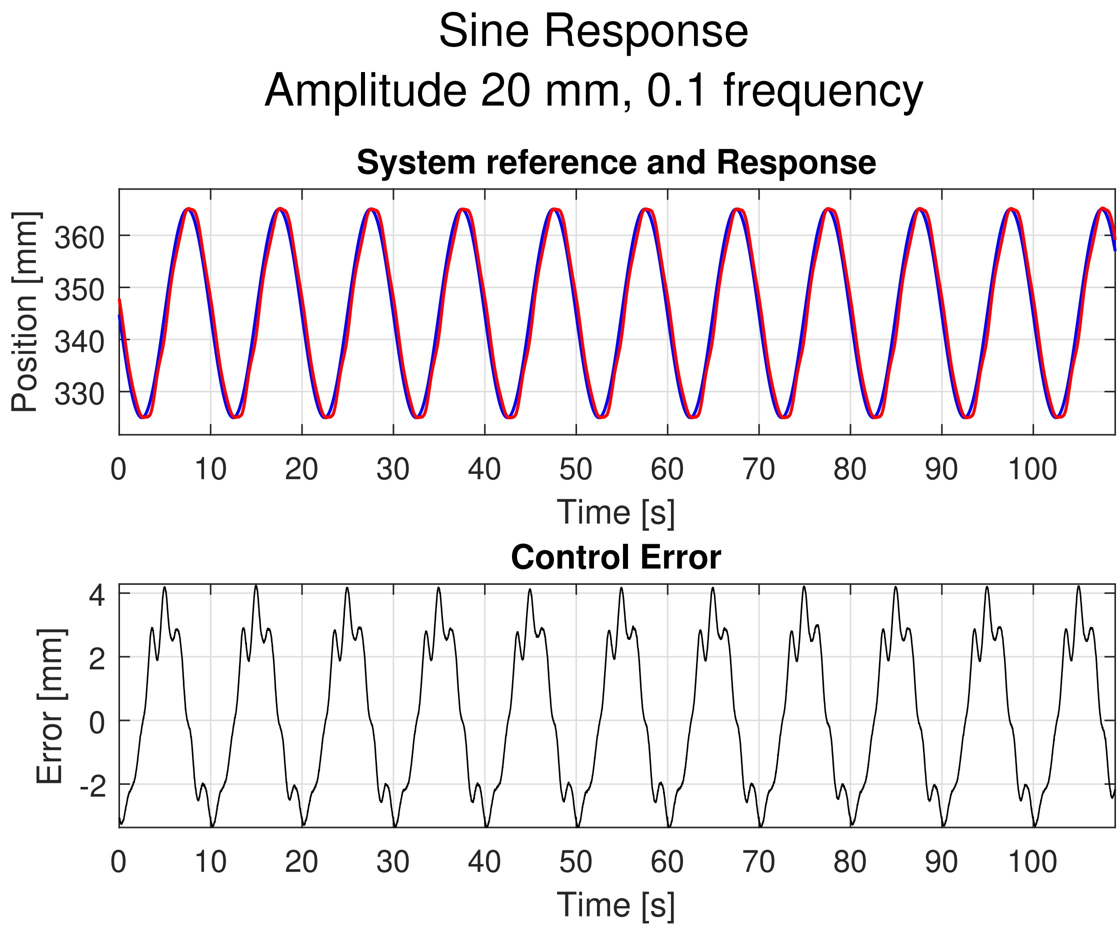


Figure 7.12: Sinusoidal motion, reference and error #1

35mm 0.1Hz Sine-wave

Max error of 6.2 *mm* meaning 83% wave compensation Wave motion of 4.0° reduced to 0.680 °. Figure 7.13 shows motion and control error.

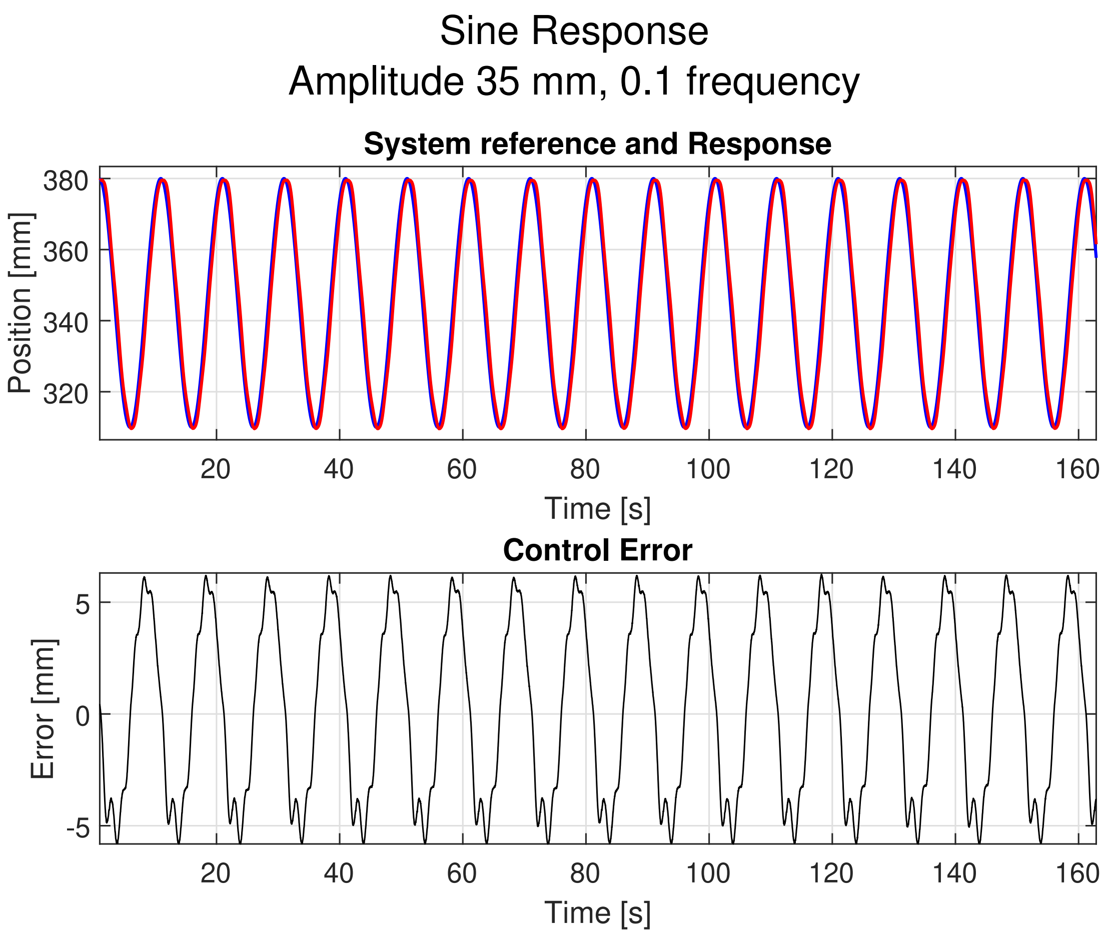


Figure 7.13: Sinusoidal motion, reference and error #2

50mm 0.1Hz Sine-wave

Max error of 8.5 mm meaning 83 % wave compensation. Wave motion of 5.0° reduced to 0.855°. Figure 7.14 shows motion and control error.

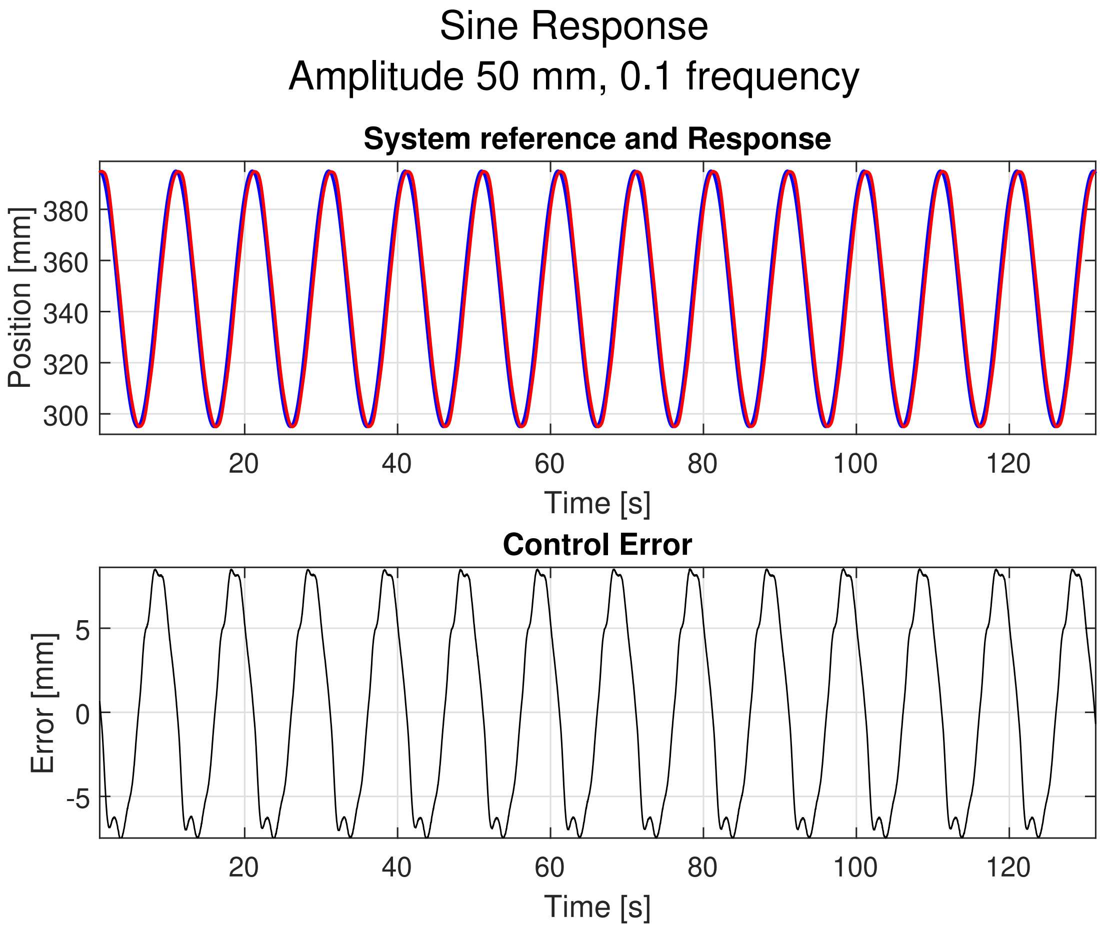


Figure 7.14: Sinusoidal motion, reference and error #3

20mm 0.2Hz Sine-wave

Maximum error of 6.3 mm meaning 69% wave compensation. Wave motion of 2.0° reduced to 0.62°. Figure 7.15 shows motion and control error.

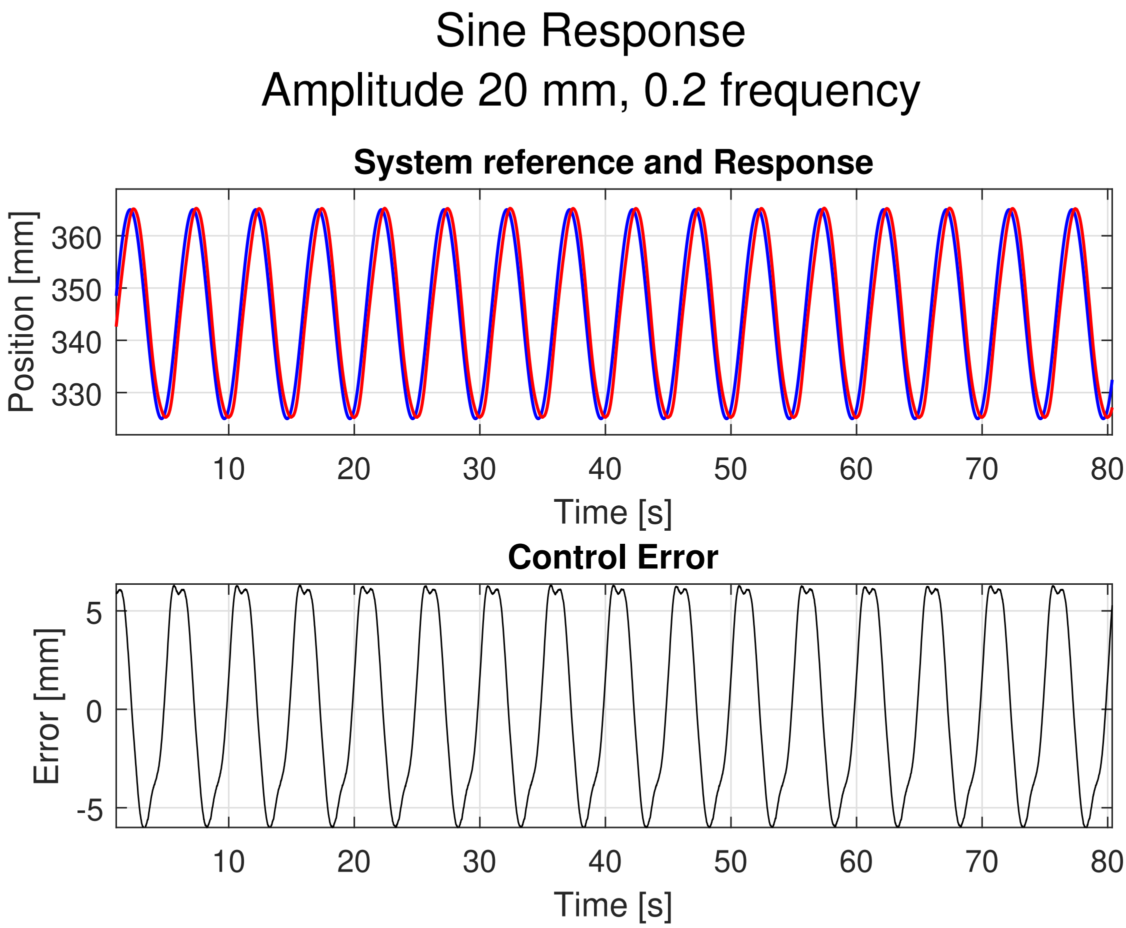


Figure 7.15: Sinusoidal motion, reference and error #4

35mm 0.2Hz Sine-wave

Maximum error of 11.9 mm meaning 66% wave compensation. Wave motion of 4.0° reduced to 1.36°. Figure 7.16 shows motion and control error.

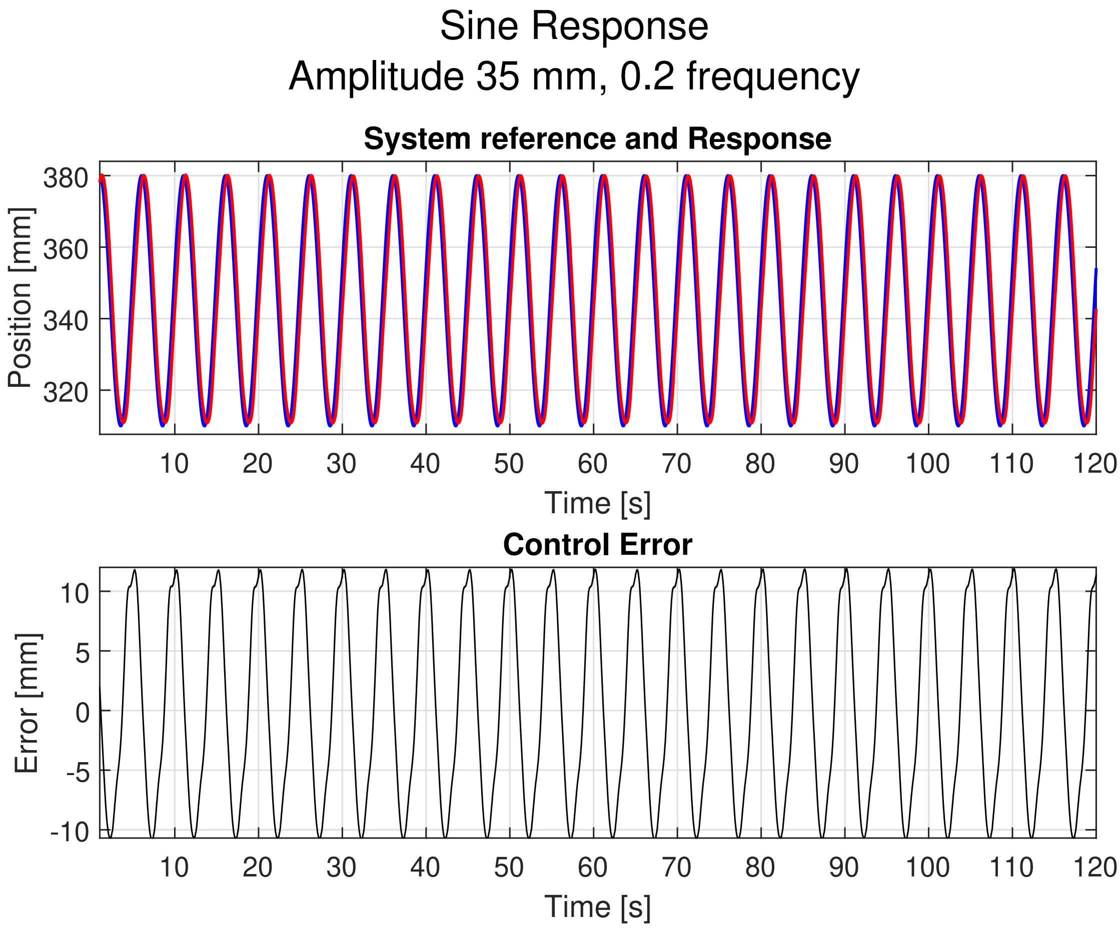


Figure 7.16: Sinusoidal motion, reference and error #5

20mm 0.25Hz Sine-wave

Maximum error of 8.8 *mm* meaning 56% wave compensation. Wave motion of 2.0° reduced to 0.80°. Figure 7.17 shows motion and control error.

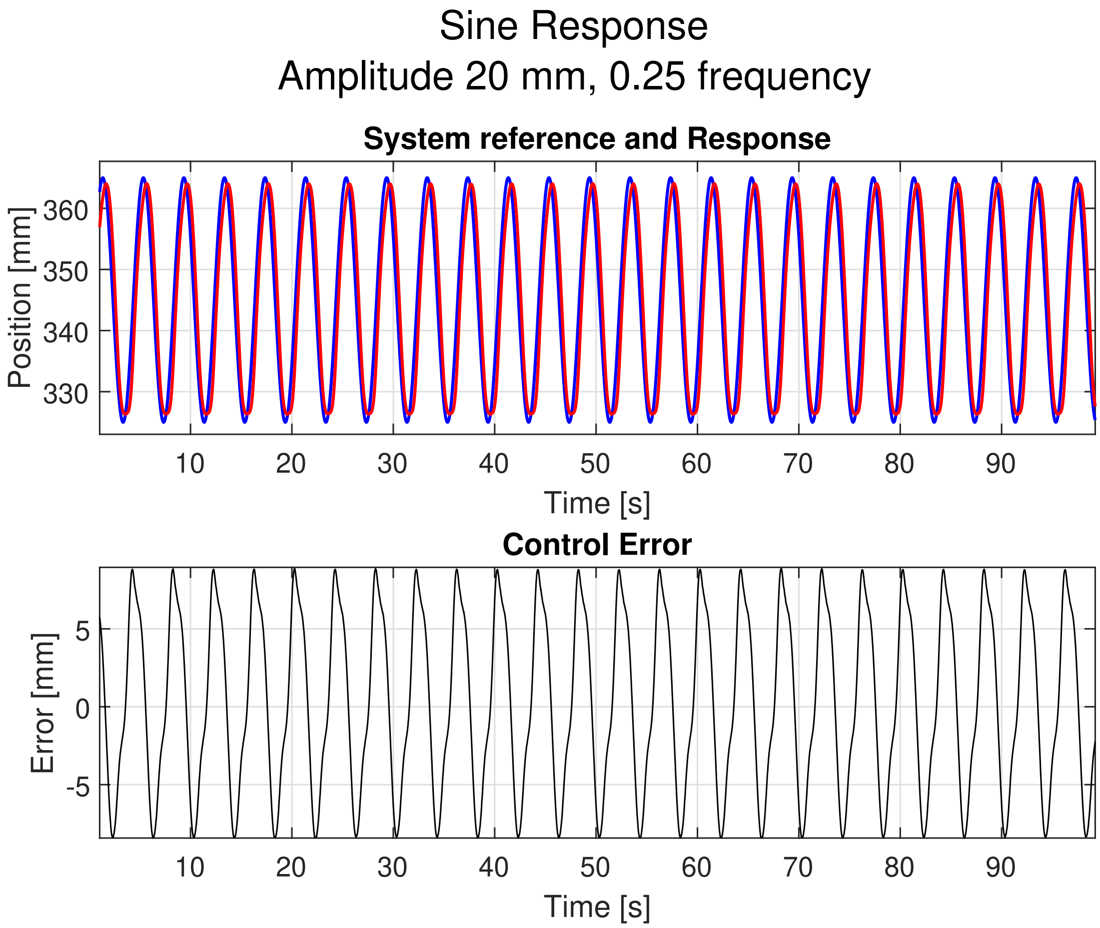


Figure 7.17: Sinusoidal motion, reference and error #6

7.2 Compared Simulation Results

This section shows the simulated systems step response overlaid with the the real step response. The pressure gain set to 1200 and p_{sum} to 10 bar. Acceleration feedback of 0.

7.2.1 2-Pump Circuit 5 Tonnes

Compared result in Figure 7.18, slight phase shift and similar characteristics for the model and simulation.

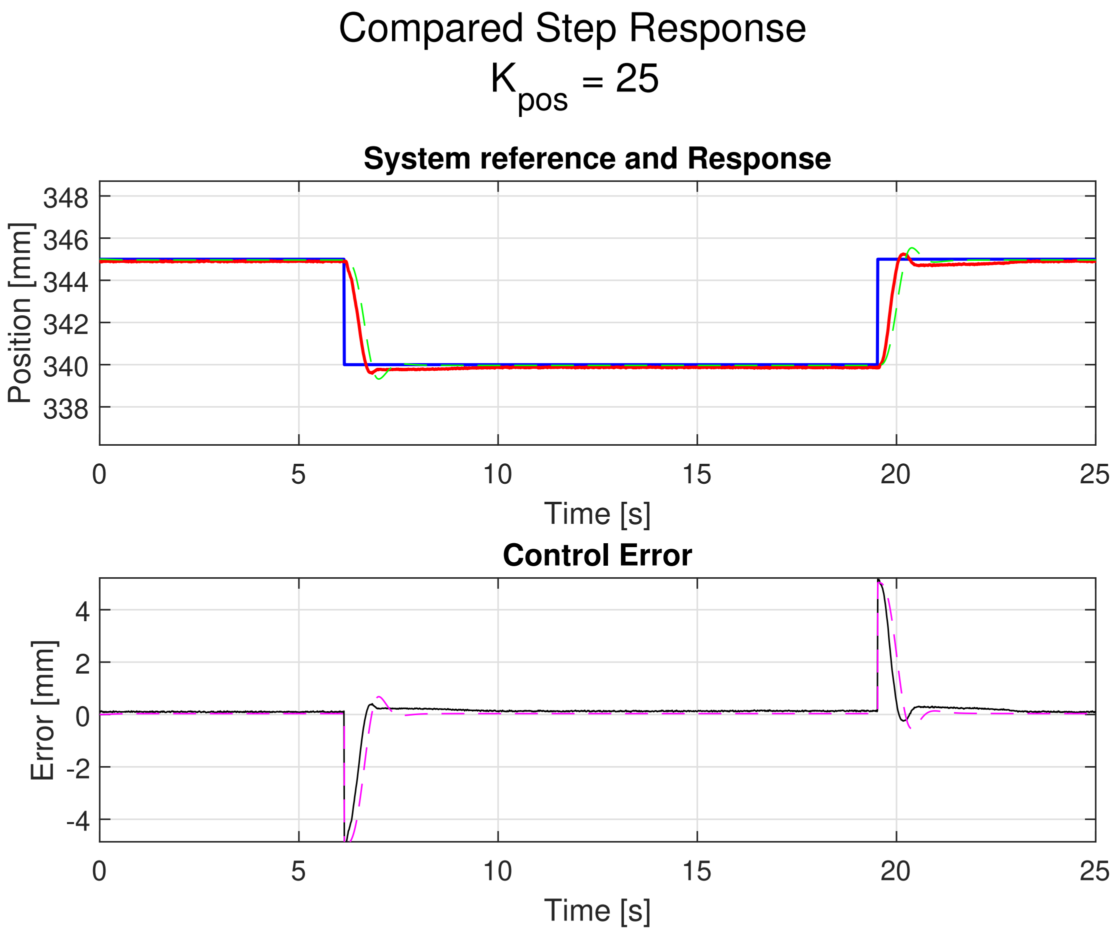


Figure 7.18: Compared step response, K_p 25

Compared result in Figure 7.19, slight phase shift and similar characteristics for the model and simulation.

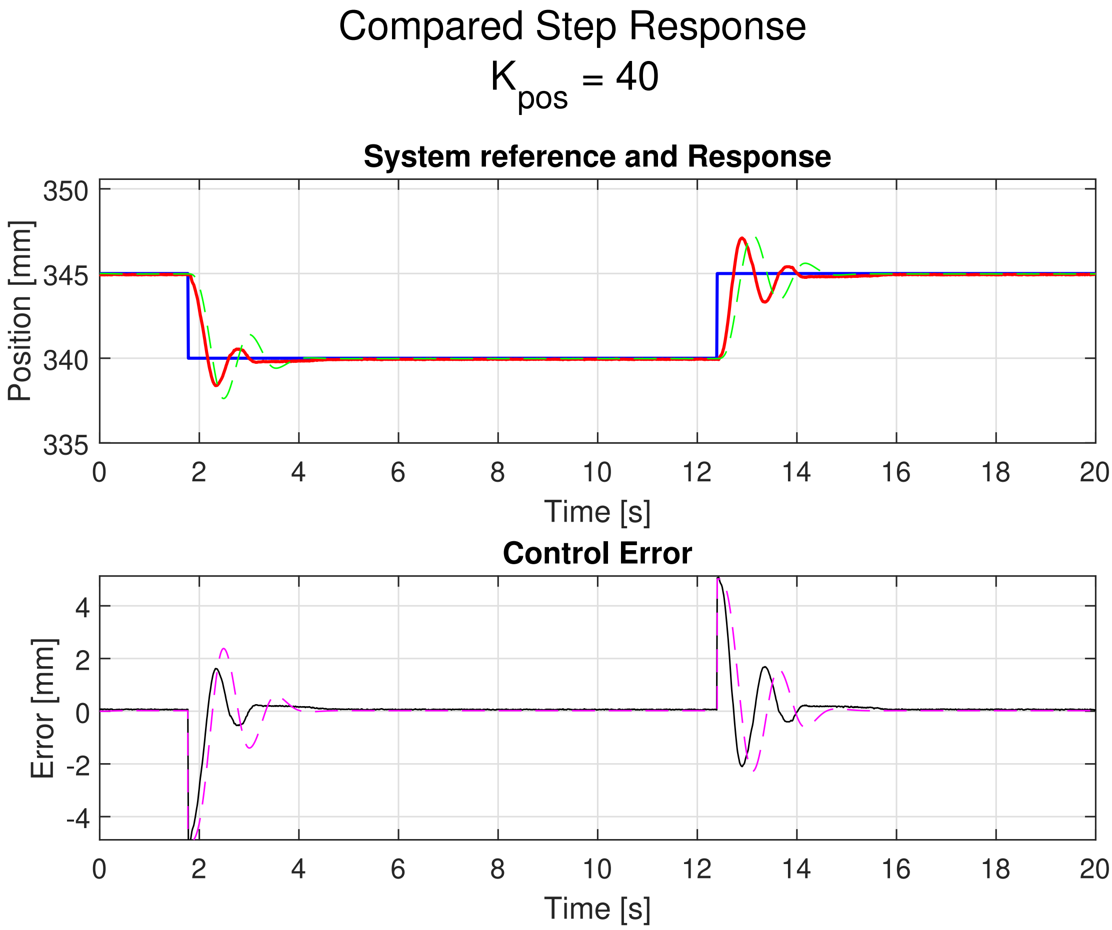


Figure 7.19: Compared step response, K_p 40

Compared result in Figure 7.20, slight phase shift and similar characteristics for the model and simulation.

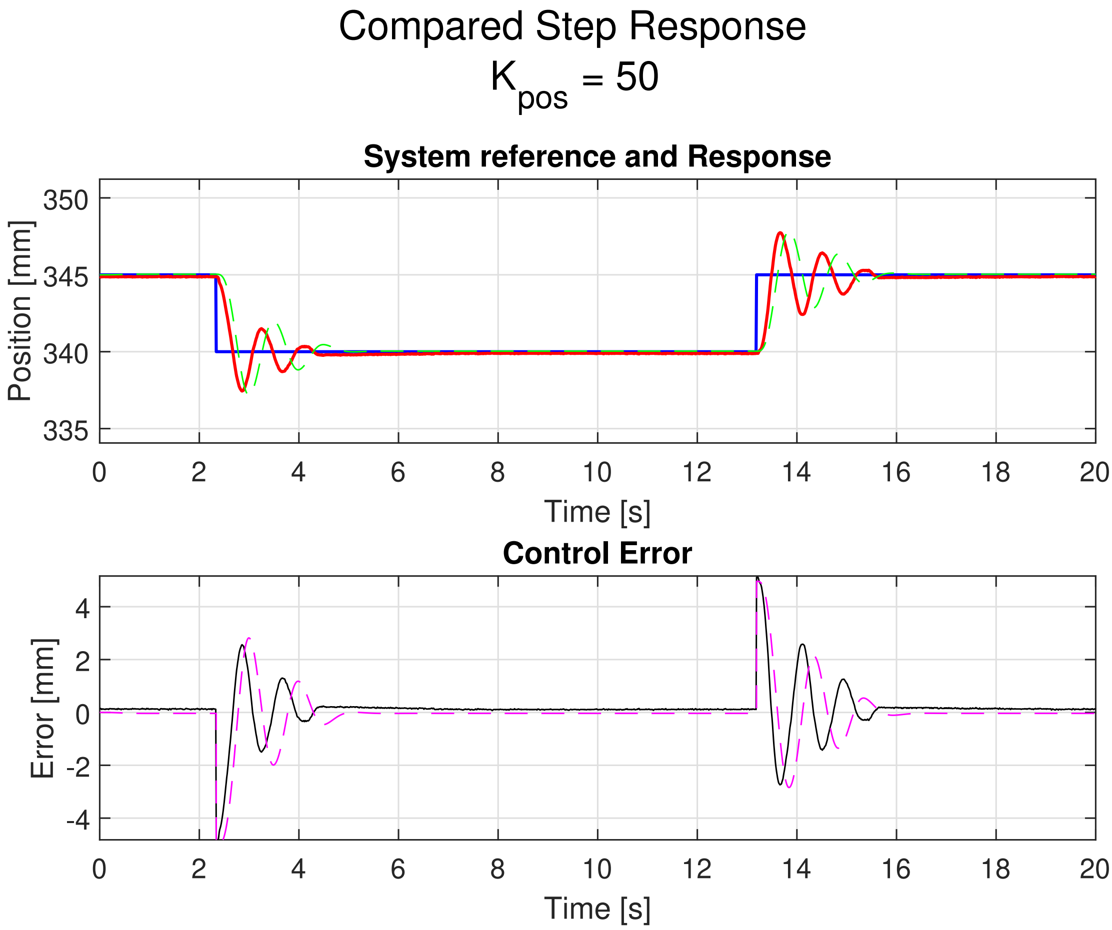


Figure 7.20: Compared step response, K_p 50

7.2.2 2-Pump Circuit 10 Tonnes

Compared result in Figure 7.21, slight phase shift and similar characteristics for the model and simulation.

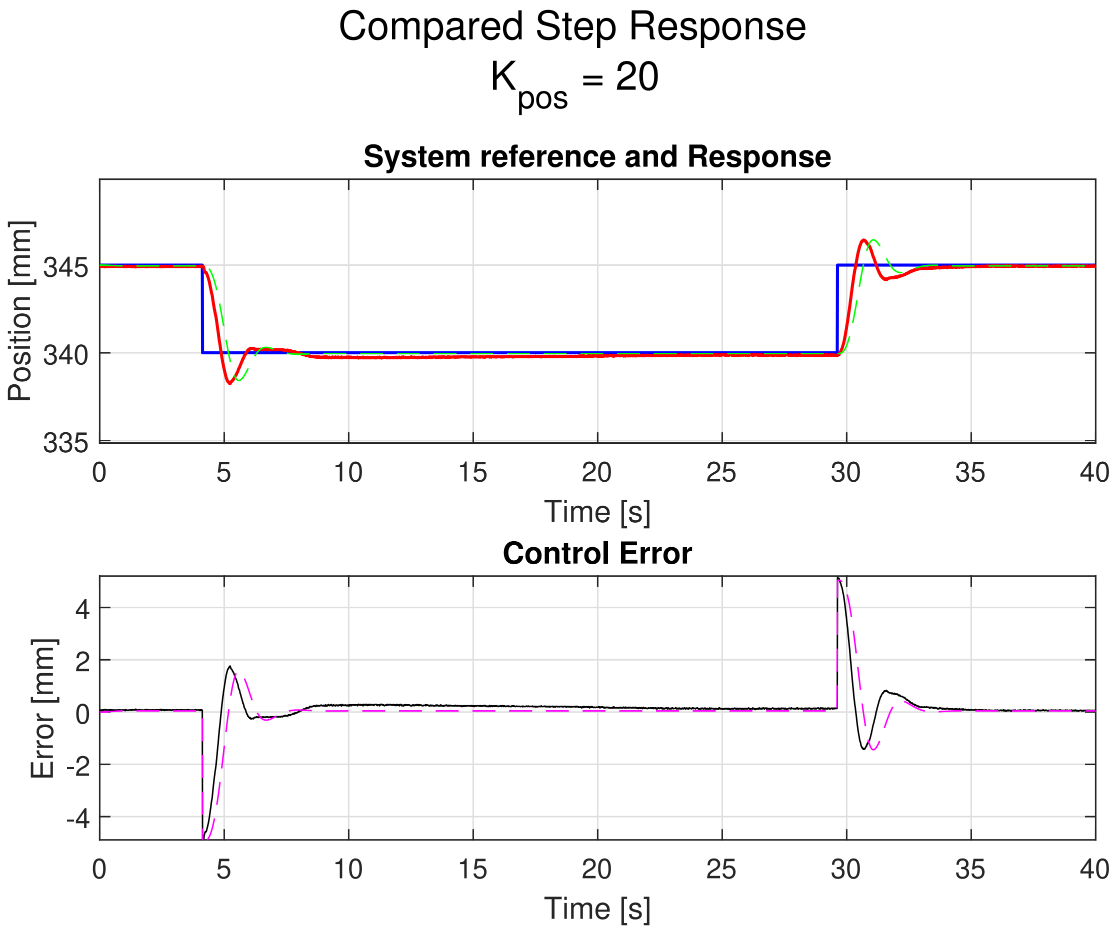


Figure 7.21: Compared step response, K_p 20

Compared result in Figure 7.22, slight phase shift and similar characteristics for the model and simulation.

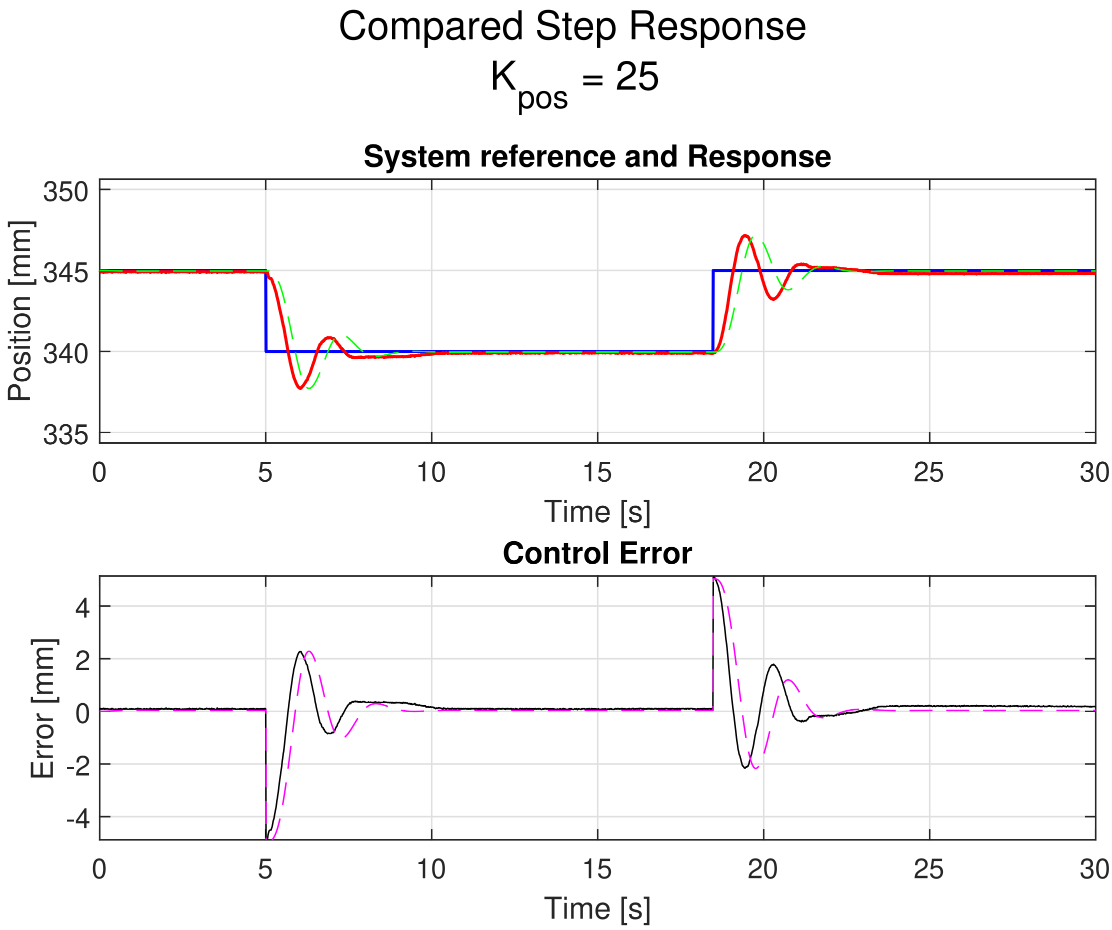


Figure 7.22: Compared step response, K_p 25

7.3 2-pump Circuit Power Consumption & Energy Usage

Each figures shows type of test and control values on figure it self. All tests are for 10 tonnes effective inertia.

20mm 0.1Hz Sine-wave

Total energy usage of $37.5kJ$, 10.4 Wh. Power usage graph shown in Figure 7.23.

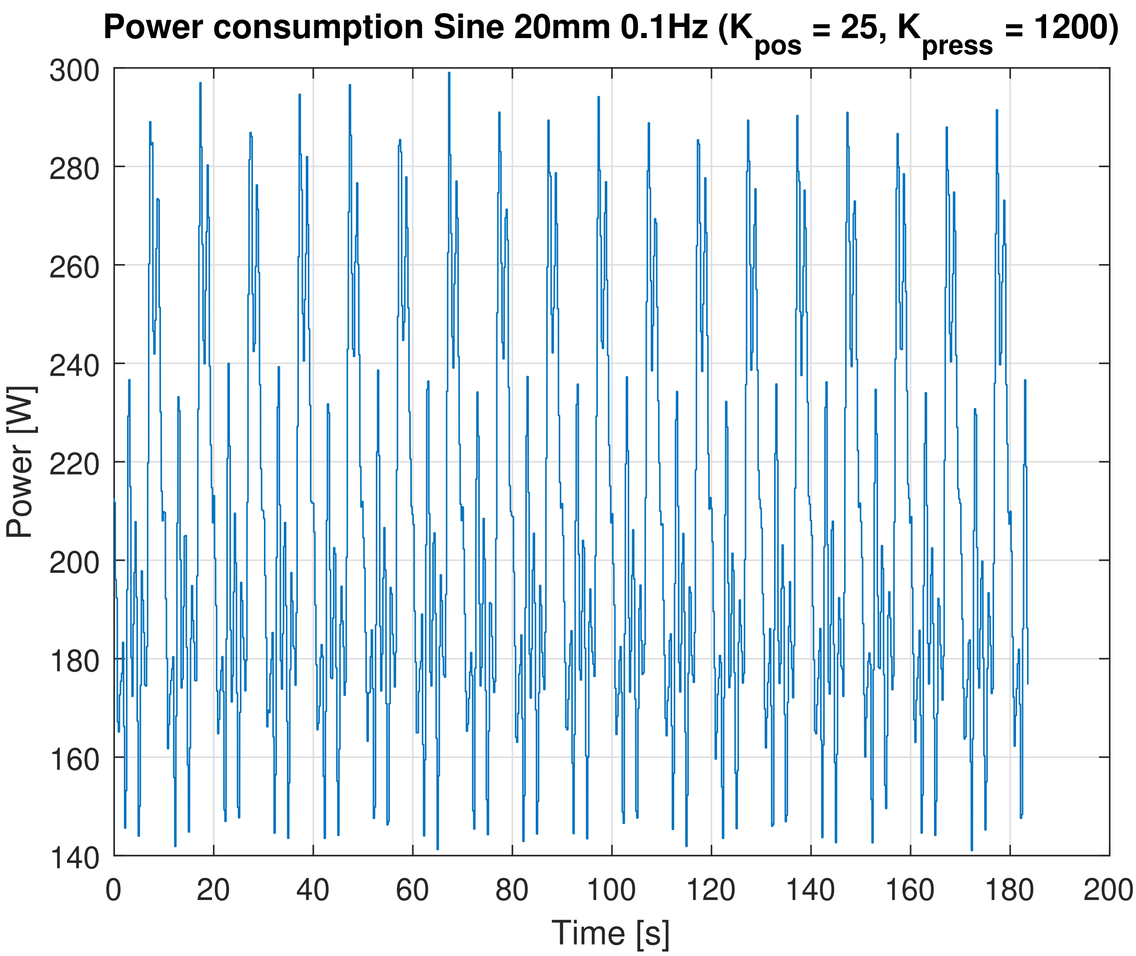


Figure 7.23: Power usage graph #1

35mm 0.1Hz Sine-wave

Total energy usage of $38.68kJ$, $10.74Wh$. Power usage graph shown in Figure 7.24.

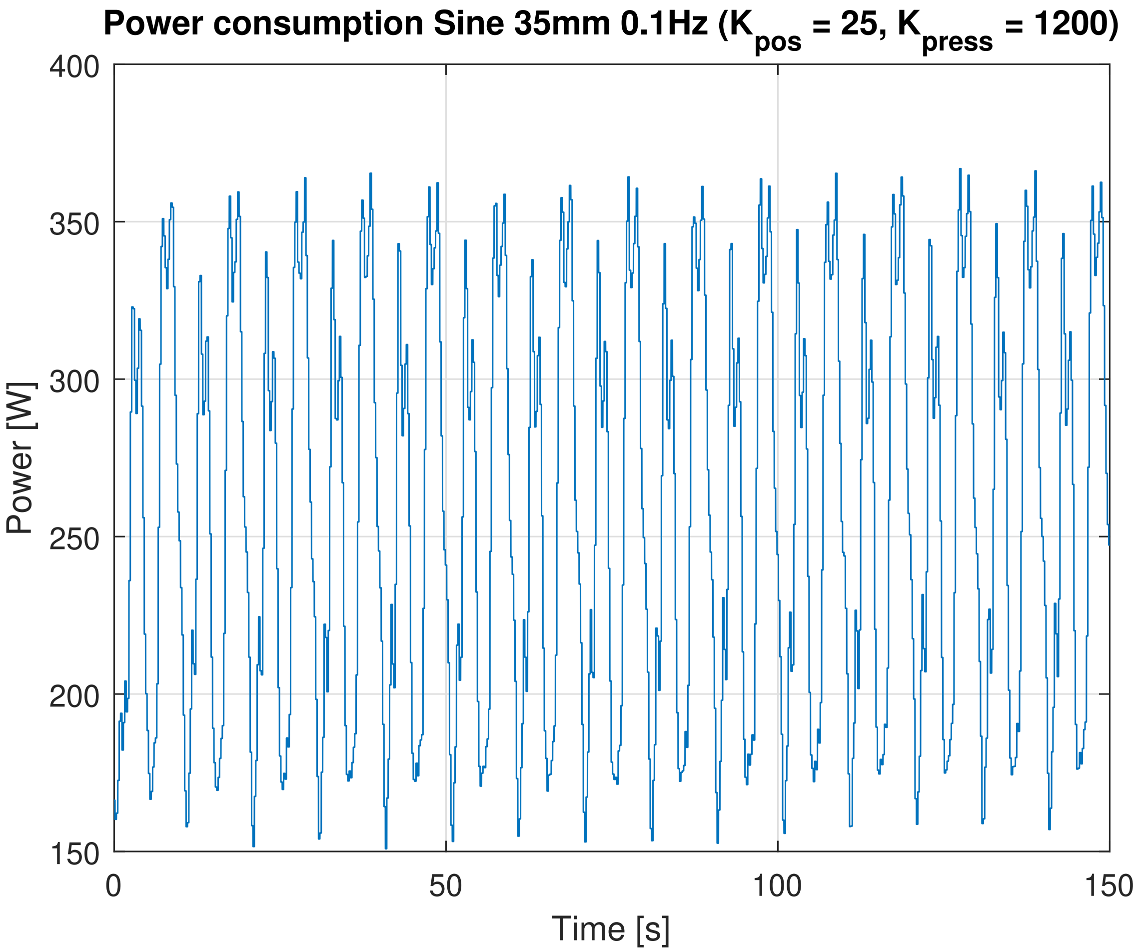


Figure 7.24: Power usage graph #2

50mm 0.1Hz Sine-wave

Total energy usage of $67.03kJ$, $18.62Wh$. Power usage graph shown in Figure 7.25.

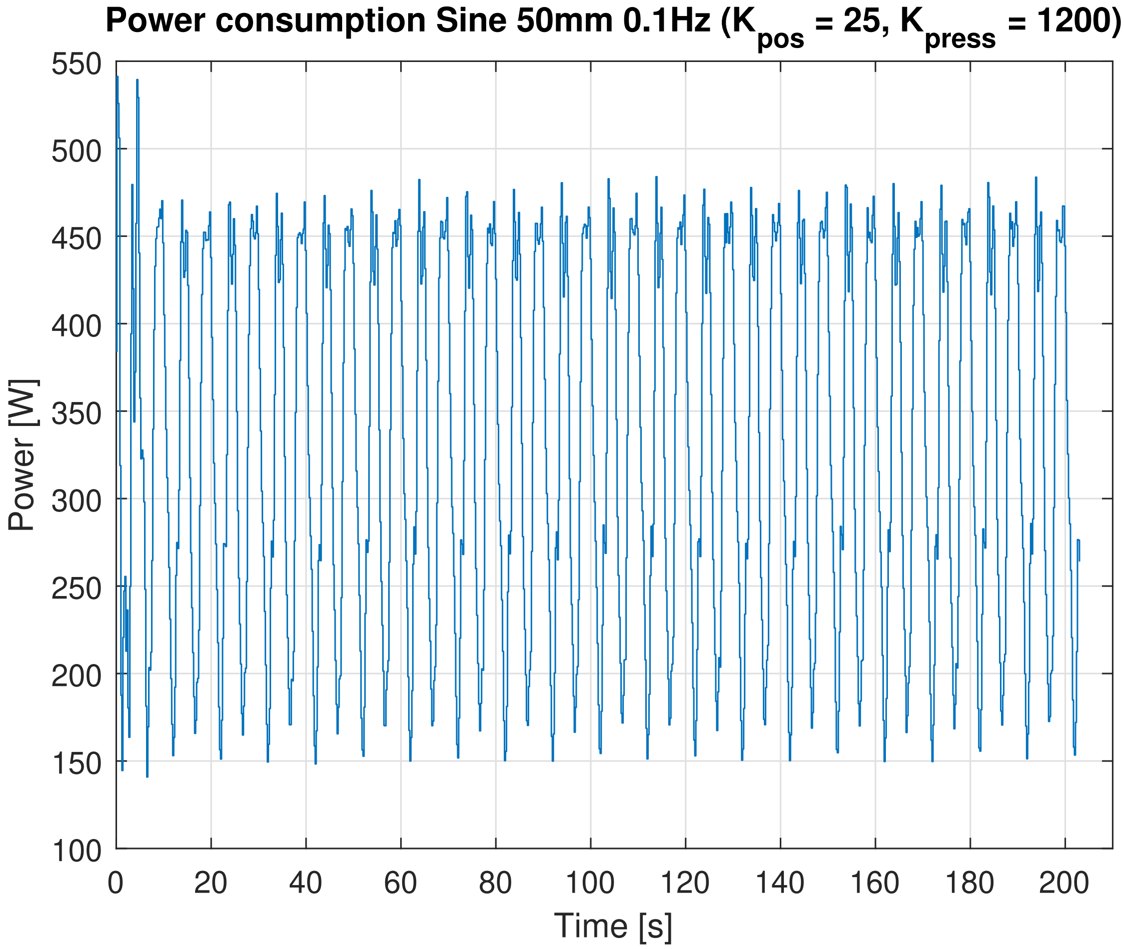


Figure 7.25: Power usage graph #3

35mm 0.2Hz Sine-wave

Total energy usage of $64.07kJ$, $17.80Wh$. Power usage graph shown in Figure 7.26. Pressure gain tuned down as fluid stiffness increased from the dissolved gasses, keeping same pressure gain as prior tests resulted in instability.

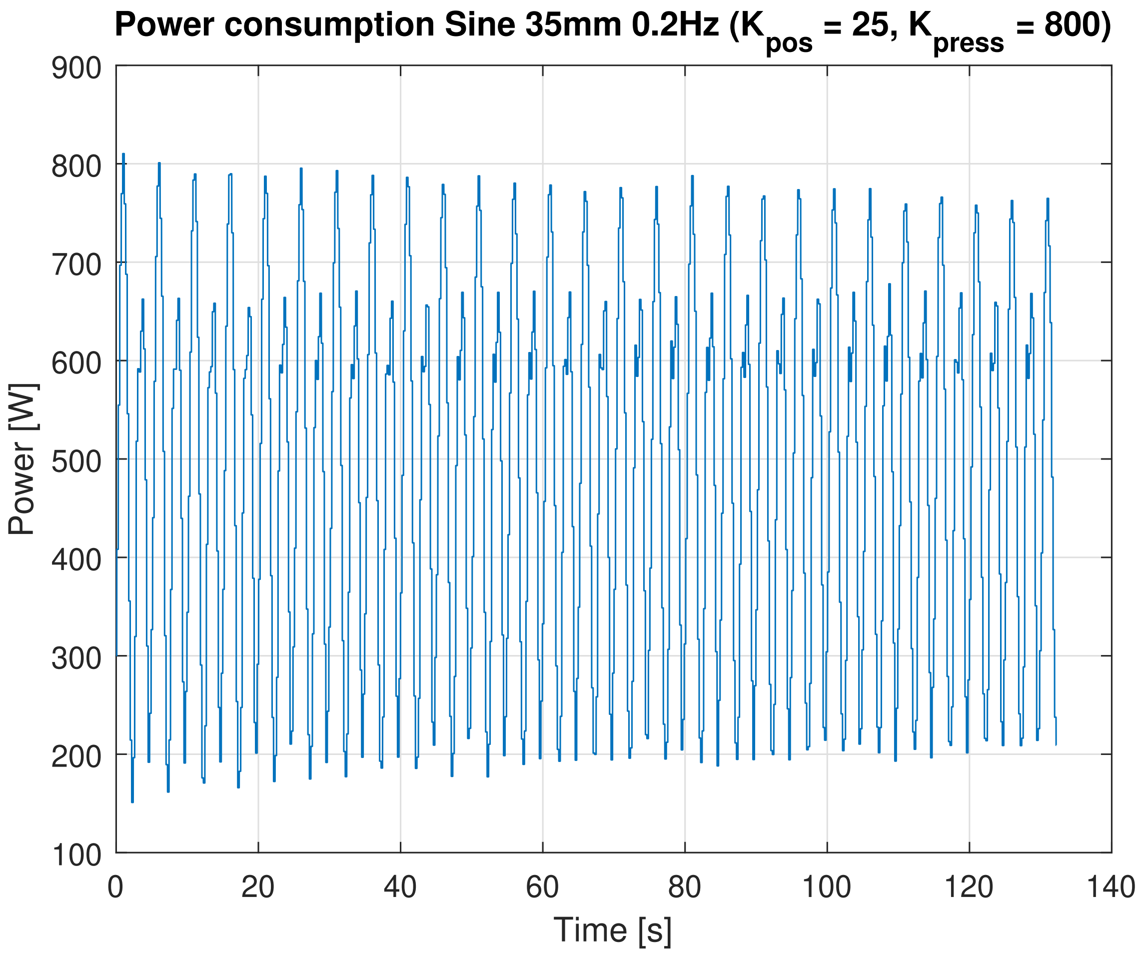


Figure 7.26: Power usage graph #4

20mm 0.25Hz Sine-wave

Total energy usage of $68.67kJ$, $19.08Wh$. Power usage graph shown in Figure 7.27. Pressure gain tuned down as fluid stiffness increased from the dissolved gasses, keeping same pressure gain as prior tests resulted in instability.

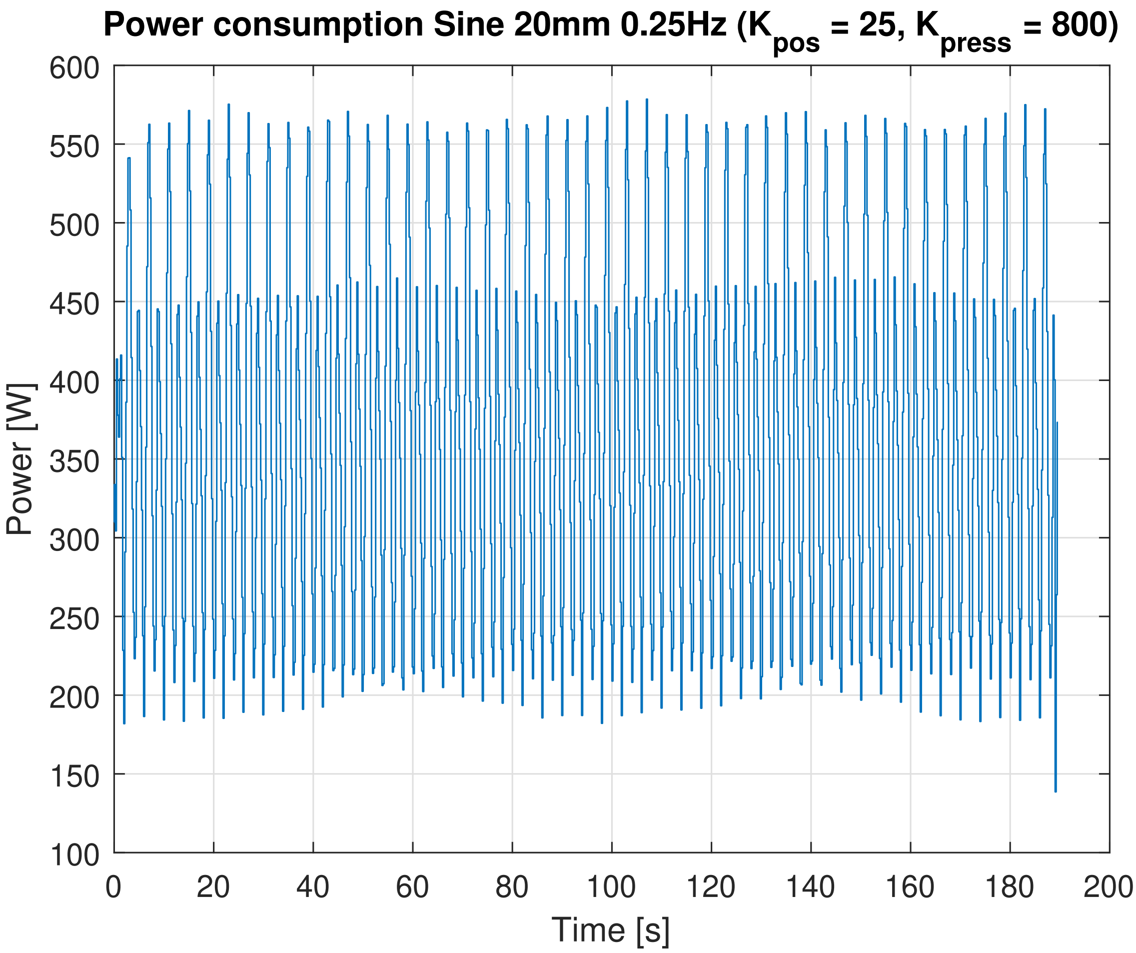


Figure 7.27: Power usage graph #5

7.4 Servo Valve Power Estimation

The estimation is for the 10 tonne effective load and the max platform velocity extracted from the logged data.

Wave type	Estimated servo valve consumption
20 mm 0.1 Hz	0.754 kW
35 mm 0.1 Hz	1.12 kW
50 mm 0.1 Hz	1.52 kW
20 mm 0.2 Hz	1.34 kW
35 mm 0.2 Hz	2.26 kW
20 mm 0.25 Hz	1.80 kW

Table 7.2: Estimated servo valve system consumption

7.5 Power comparison

This section displays the maximum power consumption measured for the 2-pump system and the estimated equivalent servo valve consumption, in Table 7.3

Wave Type	Estimated servo valve consumption	Max measured 2-pump power consumption
20 mm 0.1 Hz	0.754 kW	0.300 kW
35 mm 0.1 Hz	1.12 kW	0.367 kW
50 mm 0.1 Hz	1.52 kW	0.514 kW
35 mm 0.2 Hz	2.26 kW	0.810 kW
20 mm 0.25 Hz	1.80 kW	0.579 kW

Table 7.3: Power usage comparison table

Chapter 8

Discussion

The primary objective of this thesis has been the commissioning and testing of a 2-pump pump-controlled circuit capable of controlling effective inertias up to 10 000 kg. Initially, it was planned that only electrical work with sensors and motors be setup with a PLC, however both mechanical and hydraulic modifications and work were also necessary. With the additional work completed the entire system has been commissioned and tested, with system behavior for step- and sinusodial thoroughly documented, as requested by the client. A secondary objective has been the testing and validation of the 1-pump and servo valve circuits. These circuits did not function as intended due to design flaws in the hydraulic manifold. These circuits have therefore not been tested or documented extensively, as modifications to the manifold are outside the scope of this thesis.

A detailed simulation model has been developed for the 2-pump circuit and validated against experimental data. For model validation comparison with experimental step response was emphasized. Step response validation was chosen because a step response captures important characteristics of the system such as oscillations and damping. From the step response comparison in Chapter 7 it can be seen that the step response of the developed model follows closely that of the experimental system in both overshoot, damping and frequency of oscillations. There is a minor phase delay between model and real response, likely due to minor inaccuracies in estimation of parameters such as the bulk modulus and the resulting system stiffness. Despite this, the model is able to accurately predict and capture the oscillations as well as the increase of the oscillations that occur using larger control gains, which is the most important feature as the model because it may then be used to predict instability. This allows for the use of the model to test control algorithms and the algorithm stability in a safe environment, prior to implementation on the experimental test bed.

Position feedback has been implemented and tested experimentally for the 2-pump system by using a P-controller. A range of values for the P-controller gain has been tested and the system behavior using feedback control has been extensively tested and documented for both step- and sinusodial signals.

With position-feedback a steady state accuracy of 0.18 mm was achieved for 10 000 kg effective inertia for step-response signals, and for the same inertia up to 80% wave compensation for sinusodial signals. This very high steady-state accuracy is made possible by the low noise levels in the instrumentation of the system. The wave compensation is also satisfactory, especially considering the large inertia controlled by the system. A potential source of error in the wave compensation accuracy results is the mechanical geometry. For this thesis it was chosen to focus on cylinder position-position control, in an actual wave compensation application the platform angle is more relevant. This choice was made as the thesis focus is the hydraulic actuator and its accuracy, rather than the mechanical geometry. Despite this it is concluded that the 2-pump system is capable of achieving a good degree of wave motion compensation for frequencies up the maximum frequency specified by the client, 0.25 Hz.

For the PLC an HMI that allows for both manual actuation and feedback controlled actuation, with safety functions, real time graphing and data logging has been developed and deliver as requested by the client. As it was desired by the client to have software that allows for easy testing and simple implementation of various control algorithms, the programming language Structured Text was utilized as this is a language designed for PLCs and on the Beckhoff may be used to call "Function blocks". The ability to call function blocks means that the controller toolbox (TC3 Controller Toolbox), that uses function blocks, can be utilized for simple implementation of control algorithms. Using the developed software several data sets documenting the dynamic behavior have been supplied to the client as part of the thesis.

The energy efficiency of the 2-pump circuit has been investigated by measuring the power drawn from the grid using the Hioki power analyzer. Measuring power drawn from the grid gives a definitive answer for the systems energy consumption and serves as a good indicator on the energy efficiency of the system. The drawback of this method is that it is not possible to distinguish between electrical and hydraulic losses, which would require additional instrumentation, therefore it can not be known how much energy is lost in the electrical part versus the hydraulic part. Comparing with the theoretical minimum consumption required with a servo valve, due to the losses from from fluid throttling, it was found that the peak 2-pump consumption is 2.5-3 times smaller for 10 000 effective inertia load, with sinusodial motions. This is a significant improvement, demonstrating the capability of the 2-pump circuit to provide acceptable performance under feedback control, while being more energy efficient compared to that of a servo valve system.

Despite the unexpected challenges with the mechanical and hydraulic systems, especially the manifold issues and delay of key components, the main objective of the thesis has been achieved. All requests by the client have been fulfilled, with some of the results obtained trough this thesis scheduled to be included in one or more journal publications co-authored together with the client.

Chapter 9

Conclusions

As part of this thesis a test rig consisting of an electrohydraulic actuator controlling loads with inertia up to 10 000 kg has been prepared and commissioned.

Mechanical and hydraulic work has been performed where necessary, and an electrical setup for controlling the system has been developed with the necessary safety functions. The electrical motors have been set up and tuned according to the guidelines of the manufacturer, and an HMI complete with data logging and real-time system graphing has been developed and delivered as part of the thesis.

The 1-pump and servo valve circuits was not utilized due to issues surrounding the valve manifold block. Modifying the internals of the manifold was outside the scope of this thesis. The proposed solution is to recreate the manifold functionality outside of the manifold, then implement hydraulic changes to prevent the HPU from supplying oil to the system that is fed to the internal test bed tank.

A position control algorithm for the 2-pump system actuator has been developed, implemented and tested for effective inertia loads of 5000 kg and 10 000 kg. For the heaviest inertia a settling time of 2.3 seconds was achieved with a steady-state accuracy of 0.18 mm. For the $0.1Hz$ wave the wave motion was successfully reduced by or more than 80% for both 5000 kg and 10 000 kg inertia.

A numerical simulation model has been developed and validated by comparing against experimental data. Good agreement between the model and experimental data has been shown. Additionally, linear models have been developed, and stability margins have been examined for the 1-pump and servo valve systems.

The energy consumption of the 2-pump system has been measured using a power analyzer, and it has been shown that the energy consumption is significantly lower than the minimum theoretical consumption of a servo valve system. Experimental data and data sets for validation of the system behavior has been supplied to the client as requested.

Some of the results obtained trough this thesis are set to be included in one or more journal publications, co-authored with the client.

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[7] Damiano Padovani. “Lecture notes Hydraulic Components and Systems (MAS410).” University of Agder, 2020.

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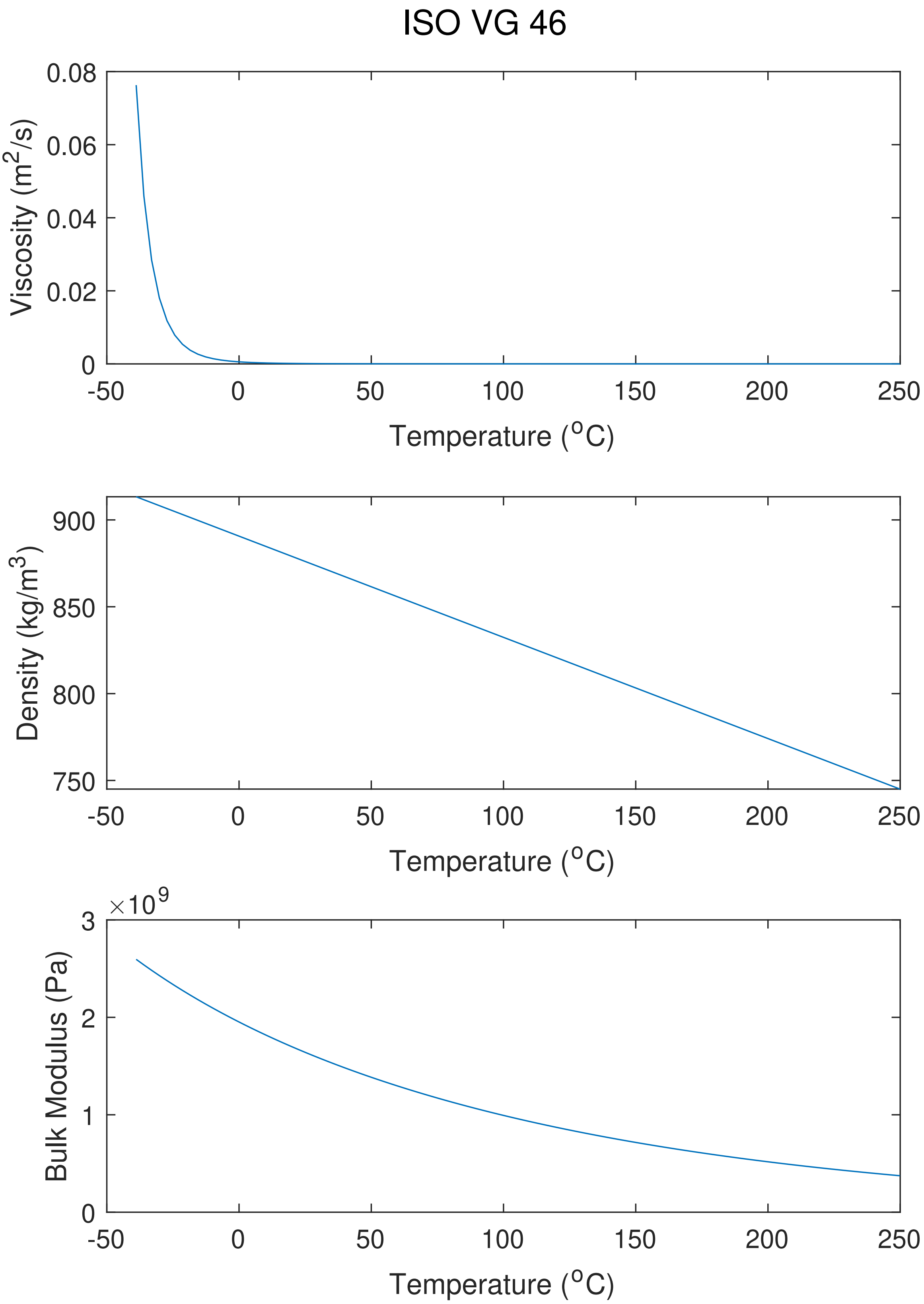
Appendix A

Miscellaneous Files

A.1 ISO VG 46 Fluid Properties

Extracted from matlab [12].

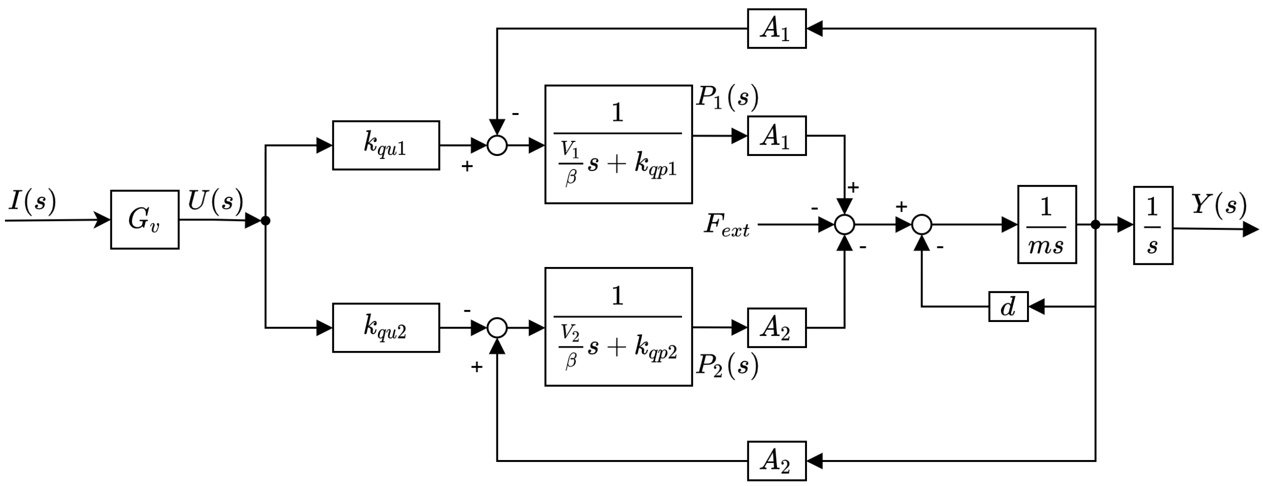

ISO VG 46
Viscosity (m²/s)
0.08
0.06
0.04
0.02
0
-50
0
50
100
150
200
250
Temperature (°C)
Density (kg/m³)
900
850
800
750
Temperature (°C)
×10⁹
Bulk Modulus (Pa)
3
2
1
0
Temperature (°C)

Appendix B

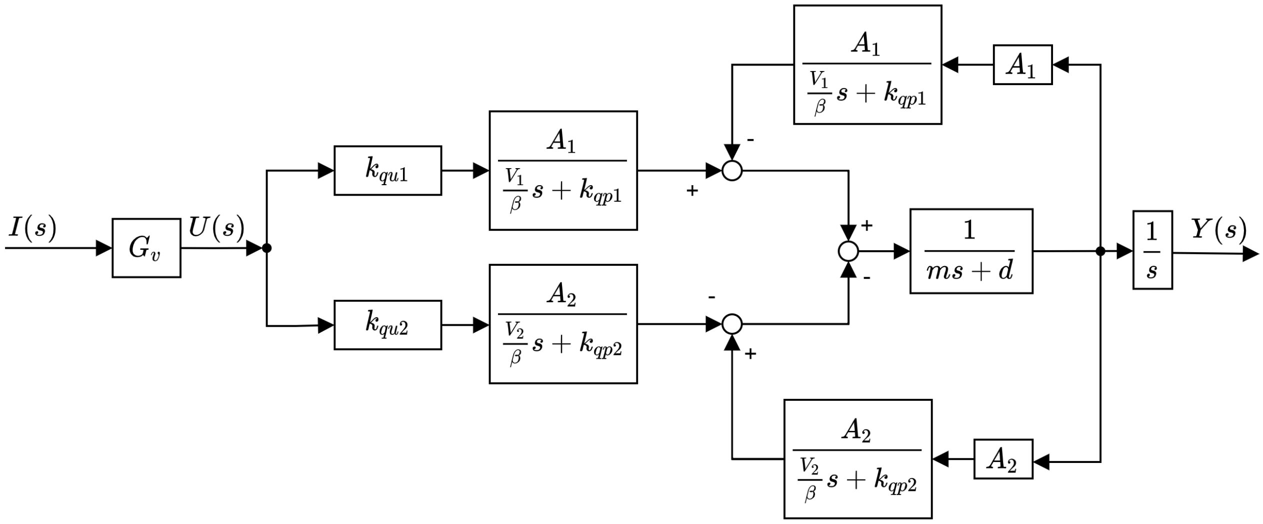
Transfer Function Derivations

B.1 Servo Valve Transfer Function

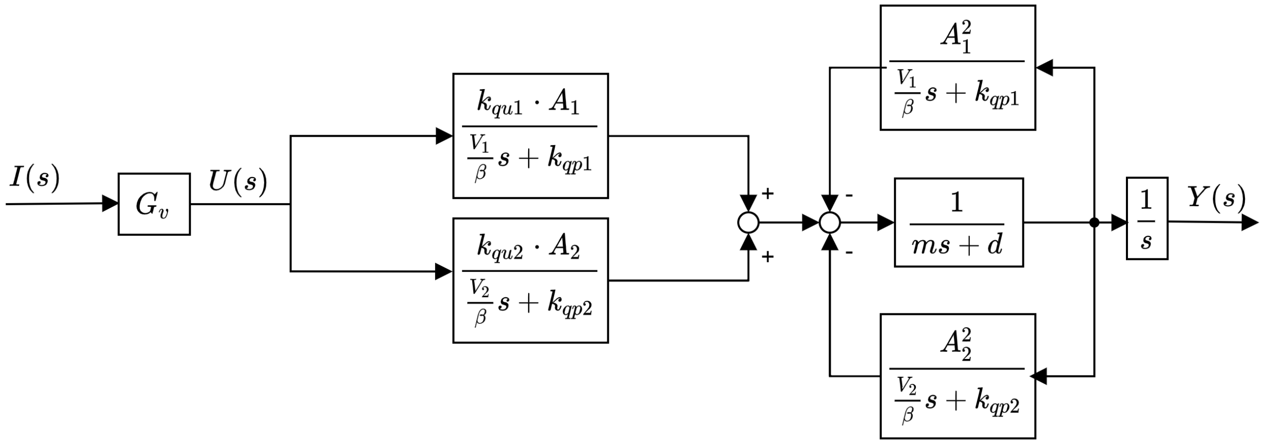
Figure below shows the entire block diagram.



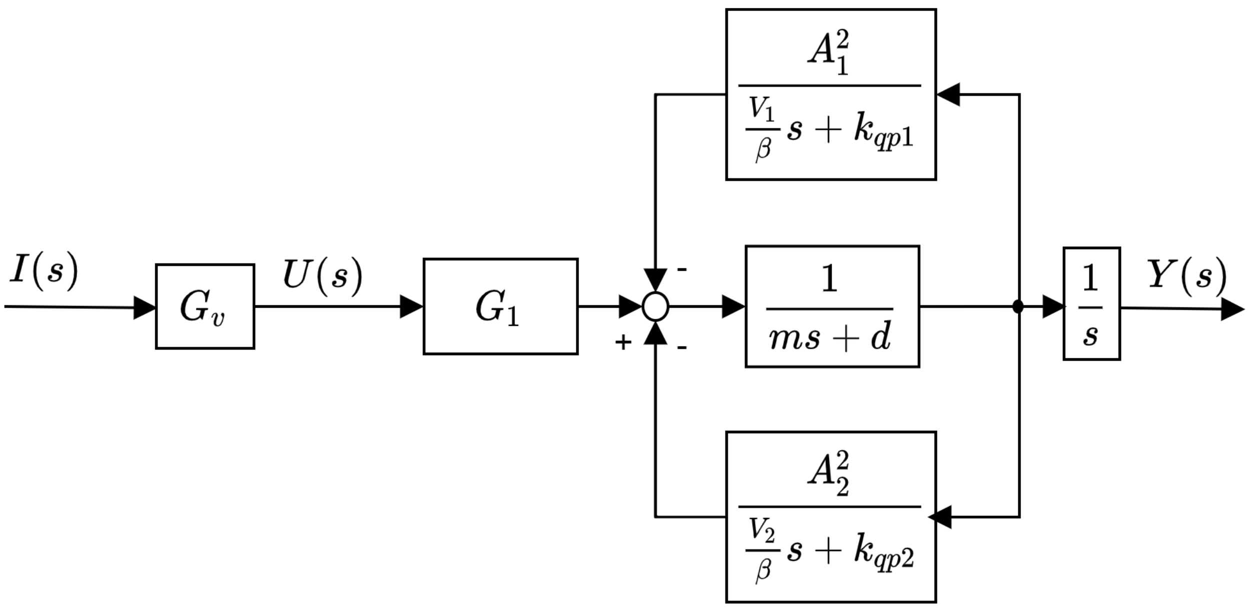
Reduced once by manipulating the A_1 and A_2 blocks as well as the damping from the system velocity.



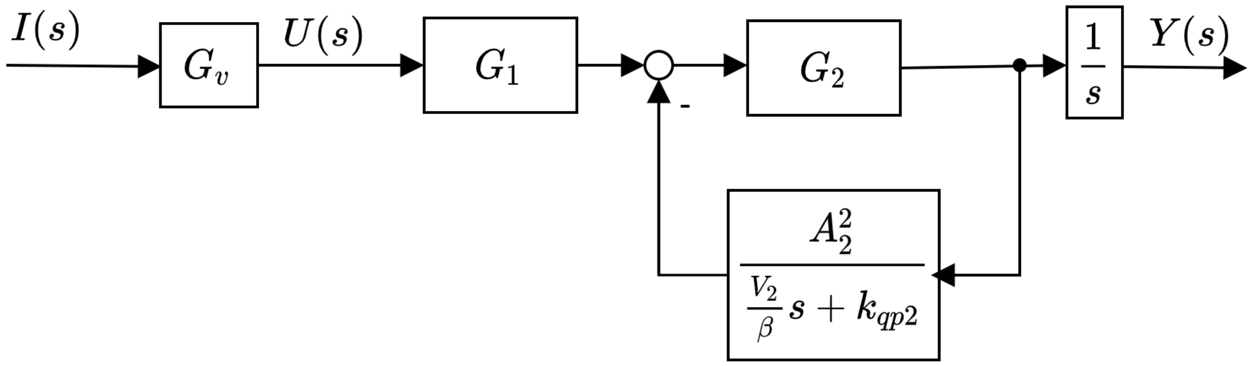
Reduced further by combining multiple terms together and mde the signs of the feedback simpler



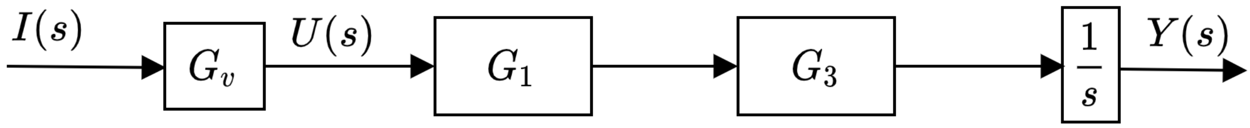
Further reduction by combing terms and naming them G_1, as well finding the equivalent blocks for the feedback



Further reduction by finally reducing the system



Final form



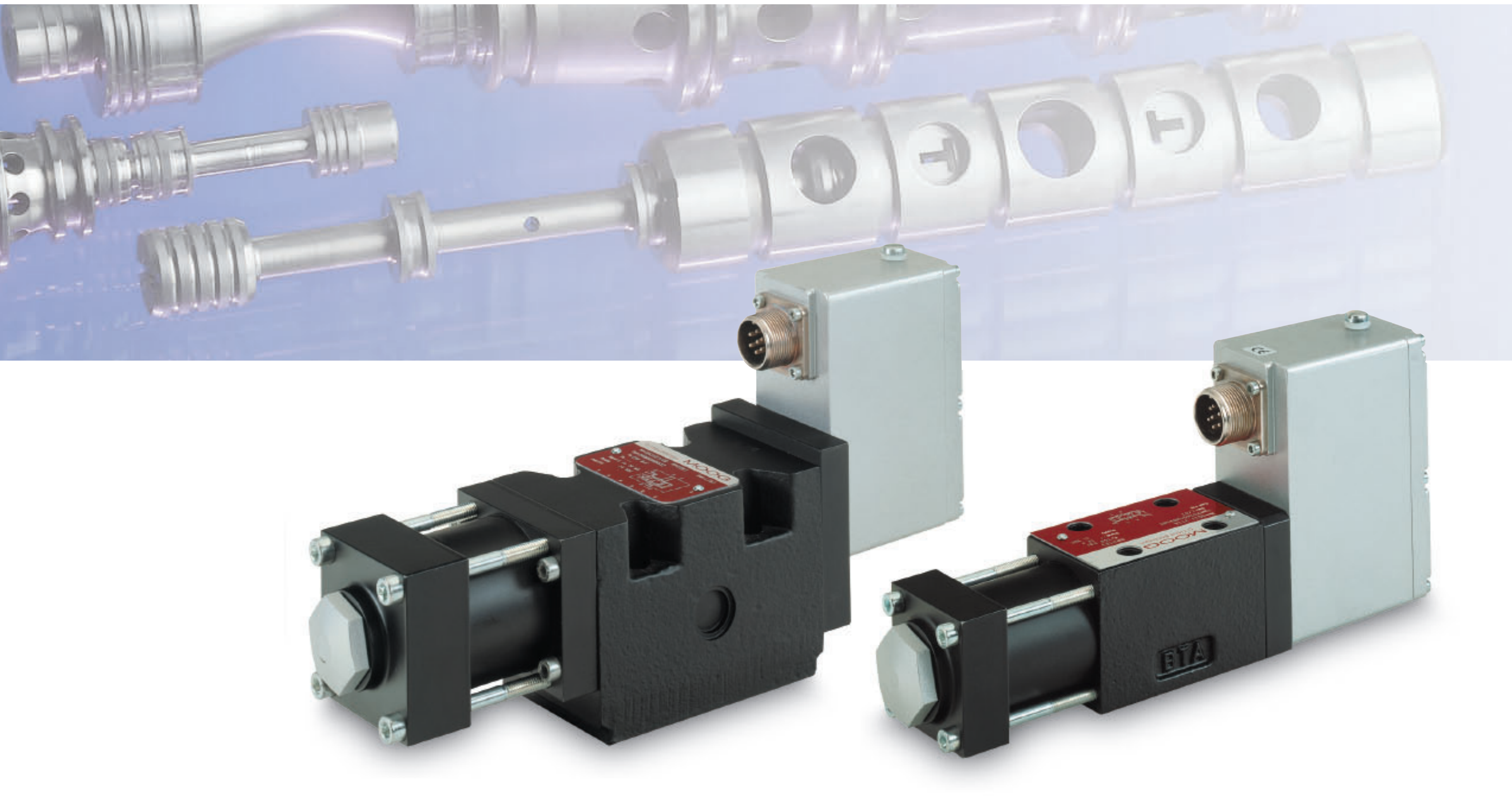
Appendix C

Datasheets

C.1 Servovalve Moog D63

MOOG

D633 and D634 Series Direct Drive
Servo-Proportional Control Valves
with integrated 24 V Electronics
ISO 4401 Size 03 and 05



GENERAL

D633-D634

MOOG SERVO- AND PROPORTIONAL CONTROL VALVES

For over 25 years Moog has manufactured proportional control valves with integrated electronics. During this time more than 150,000 valves have been delivered. These servo control valves have been proven to provide reliable control including injection and blow molding equipment, die casting machines, presses, heavy industry equipment, paper and lumber processing and other applications.

D633 AND D634 SERIES SERVO CONTROL VALVES

The D633 and D634 Series are Direct Drive Valves (DDV) with electric closed loop spool position control.
These valves are throttle valves for 3-, 4-, and 2x2-way applications. They are suitable for electrohydraulic position, velocity, pressure or force control systems including those with high dynamic response requirements.
The spool drive device is a permanent magnet linear force motor which can actively stroke the spool from its spring centered position in both directions. This is an advantage compared with proportional solenoids with one force direction only. The closed loop spool position electronics and pulse width modulated (PWM) drive electronics are integrated into the valve.
The integrated electronics of the valves is a new development featuring SMD technology with pulse width modulated (PWM) current output stage and requires a 24 VDC power supply.

CE

The valve series described in this catalogue have successfully passed EMC tests required by EC Directive. Please refer to the respective references in the electronics section.

Ex

Valves available with explosion protection to EN 50018 and 55019, class II 2G EExde B+H_2 T4, DMT 00 ATEX E 037, CE 0470 for D633 series and II 2G EExde B+H_2 T3, DMT 00 ATEX E 037, CE 0470 for D634 series.
Note: Installation dimensions and electrical connection altered. Special data sheet on request.

NOTICE

- ➢ Before installation of the valve into the system, the complete hydraulic system must be flushed.
- ➢ Please read the notes in section “Electronics”, page 6.

This catalog is for users with technical knowledge. To ensure that all necessary characteristics for function and safety of the system are given, the user has to check the suitability of the products described herein. In case of doubt please contact Moog.

For the most current information, visit our website at www.moog.com/d633series or www.moog.com/d634series.

Our quality management system conforms to DIN EN ISO 9001.

BENEFITS AND FUNCTION

D633-D634

OPERATIONAL BENEFITS OF DIRECT DRIVE SERVO VALVES (DDV)

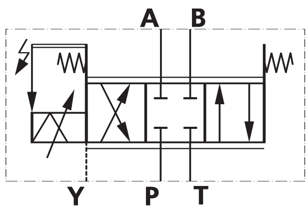
- ➢ Directly driven by a permanent magnet linear force motor with high force level
- ➢ No pilot oil flow required
- ➢ Pressure independent dynamic performance
- ➢ Low hysteresis and low threshold
- ➢ Low current consumption at and near hydraulic null
- ➢ Standardized spool position monitoring signal with low residual ripple
- ➢ Electric null adjust
- ➢ With loss of supply voltage, or broken cable, or emergency stop the spool returns to its spring centered position without passing a load move position.

DIRECT DRIVE VALVE (DDV) OPERATION

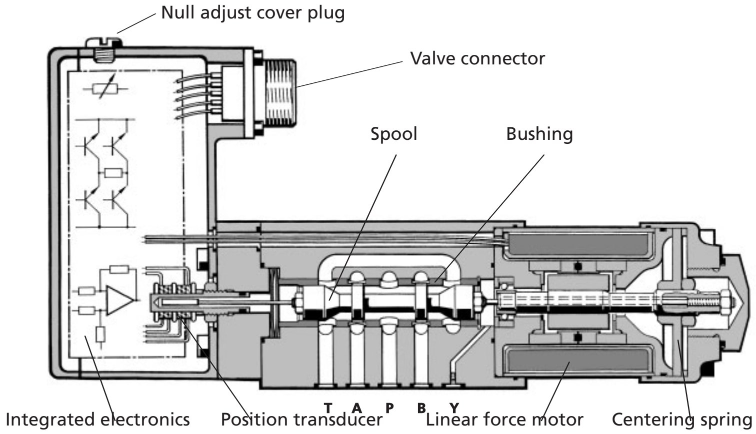
The position control loop for the spool with position transducer and linear force motor is closed by the integrated electronics. An electric signal corresponding to the desired spool position is applied to the integrated electronics and produces a pulse width modulated (PWM) current to drive the linear force motor. An oscillator excites the spool position transducer (LVDT) producing an electric signal proportional to spool position.

The demodulated spool position signal is compared with the command signal and the resulting spool position error causes current in the force motor coil until the spool has moved to its commanded position, and the spool position error is reduced to zero. The resulting spool position is thus proportional to the command signal.

D633 Series single stage
Servo Control Valve

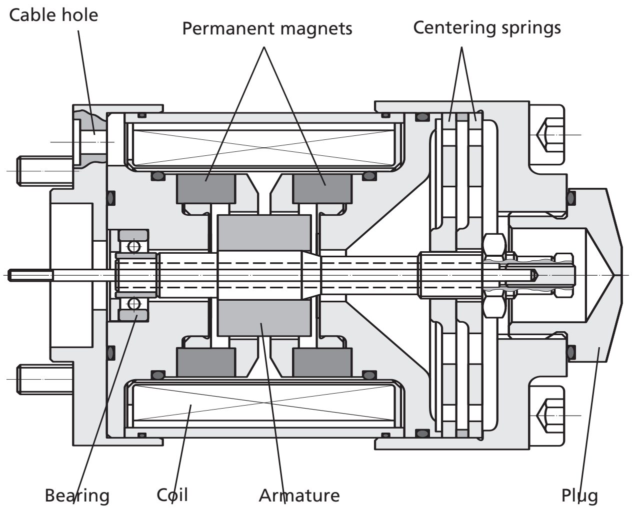


Hydraulic symbol:
Symbol shown with electric supply on and zero command signal.



PERMANENT MAGNET LINEAR FORCE MOTOR OPERATION

The linear force motor is a permanent magnet differential motor. The permanent magnets provide part of the required magnetic force. For the linear force motor the current needed is considerably lower than would be required for a comparable proportional solenoid.The linear force motor has a neutral mid-position from which it generates force and stroke in both directions. Force and stroke are proportional to current.
High spring stiffness and resulting centering force plus external forces (i.e. flow forces, friction forces due to contamination) must be overcome during out-stroking. During backstroking to centre position the spring force adds to the motor force and provides additional spool driving force which makes the valve much less contamination sensitive. The linear force motor needs very low current in the spring centered position.
Proportional solenoid systems require two solenoids with more cabling for the same function. Another solution uses a single solenoid, working against a spring. In case of current loss in the solenoid, the spring drives the spool to the end position by passing through a fully open position. This can lead to uncontrolled load movements.



GENERAL TECHNICAL DATA, SYMBOLS

D633-D634

PERFORMANCE SPECIFICATIONS FOR STANDARD MODELS

Operating pressure range

Ports P, A and B	up to 350 bar (5000 psi)
Port T	see data for individual series

Temperature range

Ambient	–20 °C to +60 °C (-4°F to +140°F)
Fluid	–20 °C to +80 °C (-4°F to +170°F)
Seal material	NBR, FPM, others on request
Operating fluid	mineral oil based hydraulic fluid (DIN 51524, part 1 to 3), others on request
Viscosity recommended	15 to 100 mm²/s
allowed	5 to 400 mm²/s

System filtration
High pressure filter (without bypass, but with dirt alarm) mounted in the main flow and if possible directly upstream of the valve.

Class of cleanliness
The cleanliness of the hydraulic fluid particularly effects the performance (spool positioning, high resolution) and wear (metering edges, pressure gain, leakage) of the servo valve.

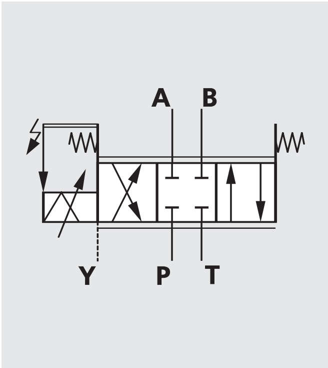
Recommended cleanliness class

For normal operation	ISO 4406 < 15 / 12
For longer life (wear)	ISO 4406 < 14 / 11

Filter rating recommended

For normal operation	β_{10} ≥ 75 (10 µm absolute)
For longer life (wear)	β_6 ≥ 75 (6 µm absolute)
Installation options	any position, fixed or movable
Vibration	30 g, 3 axes
Degree of protection	EN60529: class IP 65 with mating connector mounted
Shipping plate	Delivered with an oil sealed shipping plate

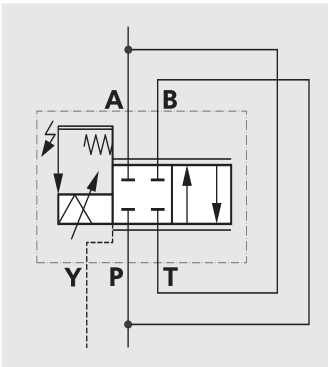
4-WAY FUNCTION



4-way version
spring centred

- ➢ Flow control (throttle valve) in port A and port B
- ➢ Port Y required if pressure p_T > 50 bar (715 psi) in port T
- ➢ for 3-way function close port A or port B of the manifold
- ➢ Spools with exact axis cut, 1,5 to 3 % or 10 % overlap available

2X2-WAY FUNCTION



2x2-way version
(Y-Port required)

- ➢ Flow control (throttle valve) in port A
- ➢ Port Y required
- ➢ Connect externally port P with port B, and port A with port T

GENERAL TECHNICAL DATA, ELECTRONICS

D633-D634

VALVE FLOW CALCULATIONS

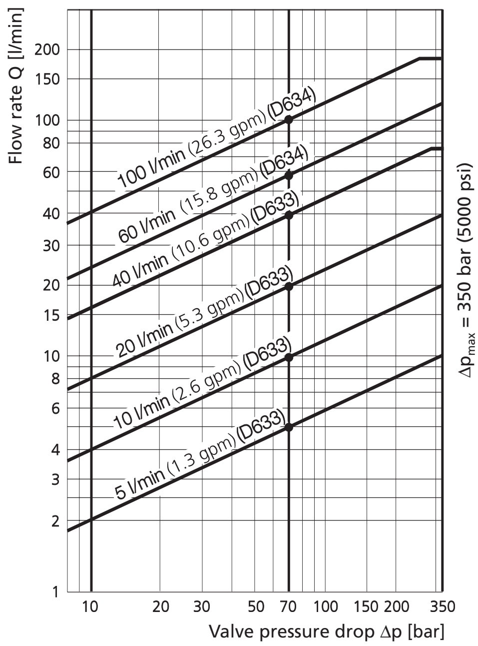
The actual valve flow is dependent on the spool position and the pressure drop across the spool lands.

At 100% command signal (i.e. +10 VDC = 100% valve opening) the valve flow at rated pressure drop Δp_N = 35 bar per metering land is the rated flow Q_N. For other than rated pressure drop the valve flow changes at constant command signal according to the square root function for sharp edged orifices.

$$Q = Q_N \cdot \sqrt{\frac{\Delta p}{\Delta p_N}}$$

Q	[l/min]	=	calculated flow
Q_N	[l/min]	=	rated flow
Δp	[bar]	=	actual valve pressure drop
Δp_N	[bar]	=	rated valve pressure drop

The real valve flow Q calculated in this way should result in an average flow velocity in ports P, A, B or T of less than 30 m/s.



GENERAL REQUIREMENTS FOR VALVE ELECTRONICS

- Supply 24 VDC, min. 19 VDC, max. 32 VDC

Current consumption I_{Amax}	for D633	1.2 A
	for D634	2.2 A
External fuse per valve	for D633	1.6 A (slow)
	for D634	2.5 A (slow)

- All signal lines, also those of external transducers, shielded.
- Shielding connected radially to ⊥ (0 V), power supply side, and connected to the mating connector housing (EMC).
- **EMC:** Meets the requirements of emission: EN55011:1998+A1:1999 (limit class: B) and immunity: EN61000-6-2:1999
- Minimum cross-section of all leads ≥ 0.75 mm^2 (0.001 in^2). Consider voltage losses between cabinet and valve.
- Note: When making electric connections to the valve (shield, protective earth) appropriate measures must be taken to ensure that locally different earth potentials do not result in excessive ground currents. See also Moog Application Note TN 353.

ELECTRONICS

D633-D634

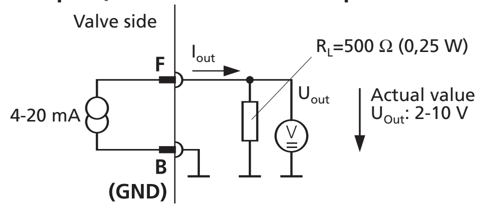
VALVE ELECTRONICS WITH 24 VOLT SUPPLY VOLTAGE AND 6+PE POLE CONNECTOR

Command signal 0 to ±10 mA
floating, Valves with current command input
The spool stroke of the valve is proportional to $I_D = -I_E$.
100 % valve opening P ➧ A and B ➧ T is achieved at I_D = +10 mA. At 0 mA command the spool is in centered position. The input pins D and E are inverting. Either pin D or E is used according to the required operating direction. The other pin is connected to signal ground at cabinet side.

Command signal 0 to ±10 V,
Valves with voltage command input
The spool stroke of the valve is proportional to $(U_D - U_E)$.
100 % valve opening P ➧ A and B ➧ T is achieved at $(U_D - U_E)$ = +10 V.
At 0 V command the spool is in centered position. The input stage is a differential amplifier. If only one command signal is avai-
lable, pin D or E is connected to signal ground at cabinet side, according to the required operating direction.

Actual value 4 to 20 mA
The actual spool position value can be measured at pin F (see diagram below). This signal can be used for monitoring and fault detection purposes.
The spool stroke range corresponds to 4 to 20 mA.
The centered position is at 12 mA. 20 mA corresponds to 100 % valve opening P ➧ A and B ➧ T . The position signal output 4 to 20 mA allows detecting a cable break, when I_F = 0 mA.

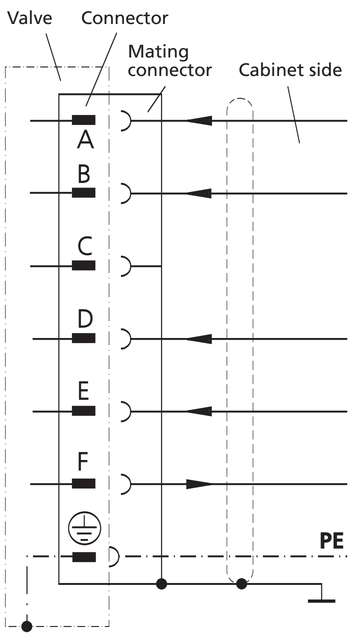
Circuit diagram for measurement of actual value I_F (position of spool) for valves with 6+PE pole connector



For failure detection purposes it is advised to connect pin F of the mating connector and route this signal to the control cabinet.

WIRING FOR VALVES WITH 6+PE CONNECTOR

to EN 175201 Part 804[1]), and mating connector (type R and S, metal shell) with leading protective earth connection (⏚).
See also Application Note AM 426 E.



Function	CurrentCommand	Voltage Command
Supply	24 VDC (19 t0 32 VDC)	
Supply / Signal Ground	⊥ (0 V)	
Not used		
Input rated command (differential)	Input command $I_D = -I_E$: 0 to ±10 mA Input command (inv.) $I_E = -I_D$: 0 to ±10 mA (R_e=200 Ω) Input voltage for U_{D-B} and U_{E-B} for both signal types is limited to min. -15 V and max. +24 V	U_{D-E} = 0 to ±10 V R_e = 10 kΩ
Output actual value spool position	I_{F-B}: = 4 to 20 mA. At 12 mA spool is in centered position. R_L =300 to 500Ω	
Protective earth		

1) formerly DIN 43563

TECHNICAL DATA

D633

PERFORMANCE SPECIFICATIONS FOR STANDARD MODELS

Model . . . Type		**D633**
Mounting pattern with or without leakage port Y [3])		ISO 4401-03-03-0-94
Port diameter	mm (in)	7.9 (0.31)
Valve version [2])		Single stage, spool in bushing 3-way, 4-way, 2x2-way
Spool actuation		directly, with permanent magnet linear force motor
Pilot supply		none
Mass	kg (lb)	2.5 (5.5)
Rated flow (±10%) at Δp_N= 35 bar [500 psi] per land	l/min (gpm)	5 / 10 / 20 / 40 (1.3 / 2.6 / 5.3 / 10.6)
Max. valve flow	l/min (gpm)	75 (19.8)
Operating pressure max.		
Ports P,A,B	bar (psi)	350 (5000)
Port T without Y	bar (psi)	50 (715)
Port T with Y	bar (psi)	350 (5000)
Port Y	bar (psi)	directly to tank
Response time for 0 to 100% stroke, typical	ms	≤ 12
Threshold [1])	%	< 0.1
Hysteresis [1])	%	< 0.2
Null shift [1]) with ΔT = 55 K	%	< 1.5
Null leakage flow [1]) max. (axis cut)	l/min (gpm)	0.15 / 0.3 / 0.6 / 1.2 (0.04 / 0.08 / 0.16 / 0.32)

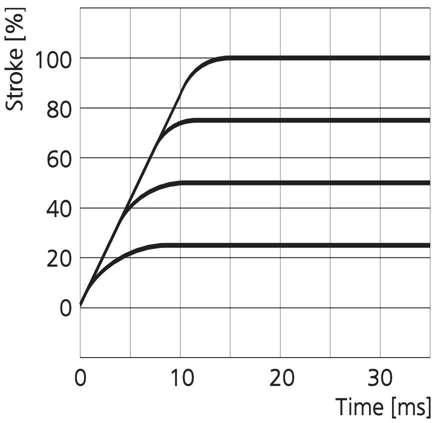
1) At operating pressure p_p = 140 bar (2000psi), fluid viscosity of 32 mm^2/s (0.05 in^2/s) and fluid temperature of 40 °C (104° F)
2) See symbols page 4
3) Leakage port Y must be used
  ➢ with 3- and 4-way function and p_T > 50 bar (715psi)
  ➢ with 2x2-way function

TECHNICAL DATA

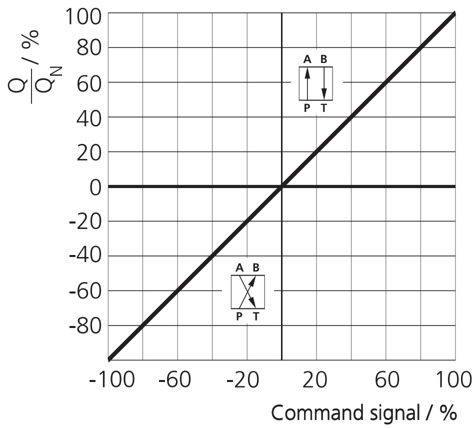
D633

CHARACTERISTIC CURVES (TYPICAL)

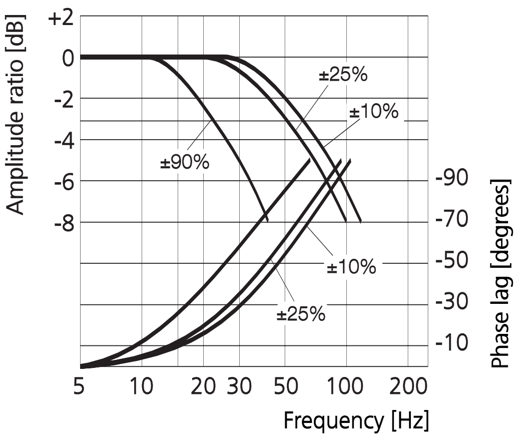
Step response



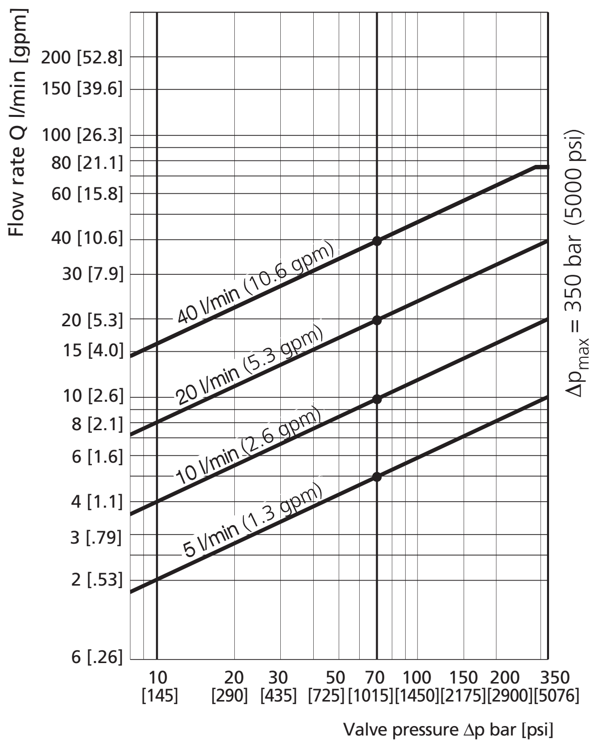
Flow signal characteristic curve



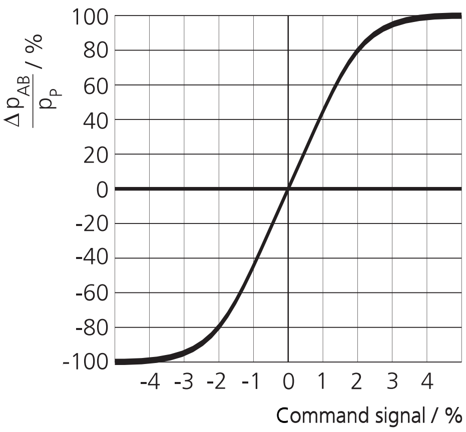
Frequency response



Valve flow diagram



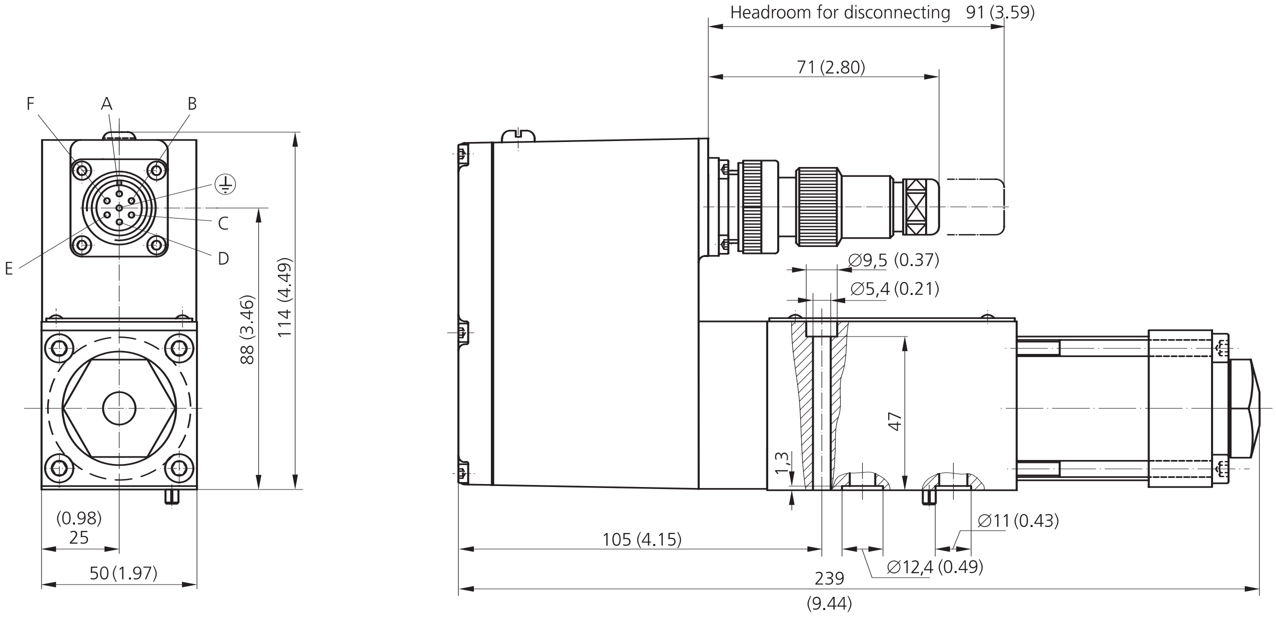
Pressure signal characteristic curve



TECHNICAL DATA

D633

INSTALLATION DRAWING



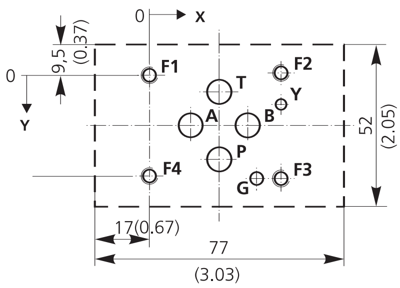
Mounting pattern
ISO 4401-03-03-0-94, without X port

mm

	P	A	B	T	X[1)]	Y	F_1	F_2	F_3	F_4	G
	Ø7,5	Ø7,5	Ø7,5	Ø7,5		Ø3,3	M5	M5	M5	M5	4
x	21,5	12,7	30,2	21,5		40,5	0	40,5	40,5	0	33
y	25,9	15,5	15,5	5,1		9	0	-0,75	31,75	31	31,75

inch

	P	A	B	T	X[1)]	Y	F_1	F_2	F_3	F_4	G
	Ø0.30	Ø0.30	Ø0.30	Ø0.30		Ø0.13	M5	M5	M5	M5	0.16
x	0.85	0.50	1.19	0.85		1.60	0	1.60	1.60	0	1.30
y	1.02	0.61	0.61	0.20		0.35	0	-0.03	1.25	1.22	1.25



1) Port X must not be drilled, not sealed at valve base.

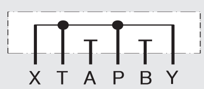
Mounting surface needs flat within 0,01 mm (0.0004 in) over a distance of 100 mm (3.94 in). Average surface finish value, Ra = 0.8 µm.

Spare parts and Accessories

O-Rings (included in delivery) — NBR 90 Shore / FPM 90 Shore
- for ports P,T,A,B — 4 pieces ID 9,25 x Ø 1,8 (ID 0.36 x Ø 0.07) — 45122–013 — 42082–013
- for port Y — 1 piece ID 7,65 x Ø 1,8 (ID 0.30 x Ø 0.07) — 45122–012 — 42082–012

Mating connector, waterproof IP65 (not included in delivery) — for cable dia min. Ø 10 mm (0.394 in), max. Ø 12 mm (0.472 in)
- 6+PE-pole — B97007 061 — EN 175201 Part 804

Flushing plates — for P,A,B,T,X,Y — B46634 002



Mounting manifolds — on request

Mounting bolts (not included in delivery) — required torque — required
M 5 x 55 DIN EN ISO 4762-10.9 — A03665 050 055 — 8.5 Nm (75 inch pounds) — 4 pieces

TECHNICAL DATA

D634

PERFORMANCE SPECIFICATIONS FOR STANDARD MODELS

Model . . . Type		**D634**
Mounting pattern with or without leakage port Y [3])		ISO 4401-05-05-0-94
Port diameter	mm (in)	11.5 (0.45)
Valve version [2])		Single stage, spool in bushing 3-way, 4-way, 2x2-way
Spool actuation		directly, with permanent magnet linear force motor
Pilot supply		none
Mass	kg (lb)	6.3 (13.9)
Rated flow (±10%) at Δp_N= 35 [500 psi] bar per land	l/min (gpm)	60 / 100 (15.8 / 26.3)
Max. valve flow	l/min (gpm)	185 (48.8)
Operating pressure max.		
Ports P,A,B	bar (psi)	350 (5000)
Port T without Y	bar (psi)	50 (715)
Port T with Y	bar (psi)	350 (5000)
Port Y	bar (psi)	directly to tank
Response time for 0 to 100% stroke, typical	ms	≤ 20
Threshold [1])	%	< 0.1
Hysteresis [1])	%	< 0.2
Null shift [1]) with ΔT = 55 K	%	< 1.5
Null leakage flow [1]) max. (axis cut)	l/min (gpm)	1.2 / 2.0 (0.26 / 0.43)

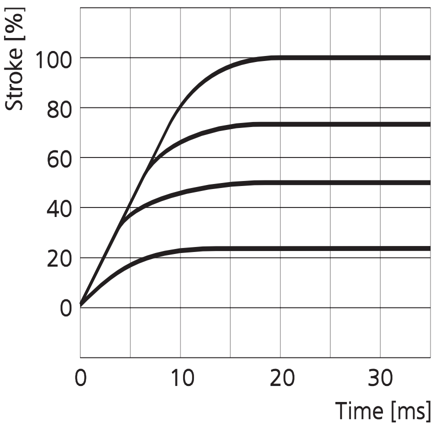
1) At operating pressure p_p = 140 bar (2000 psi), fluid viscosity of 32 mm^2/s (0.05 in^2/s) and fluid temperature of 40 °C (104° F)
2) See symbols page 4
3) Leakage port Y must be used
   ➢ with 3- and 4-way function and p_T > 50 bar (715 psi)
   ➢ with 2x2-way function

TECHNICAL DATA

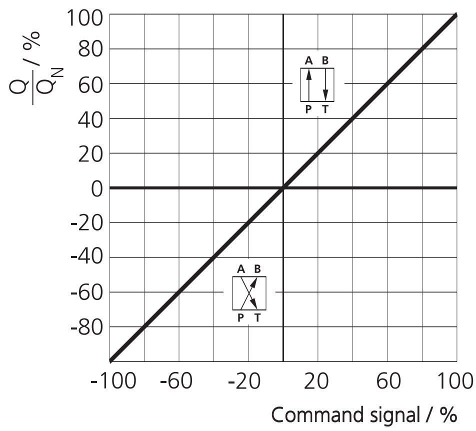
D634

CHARACTERISTIC CURVES (TYPICAL)

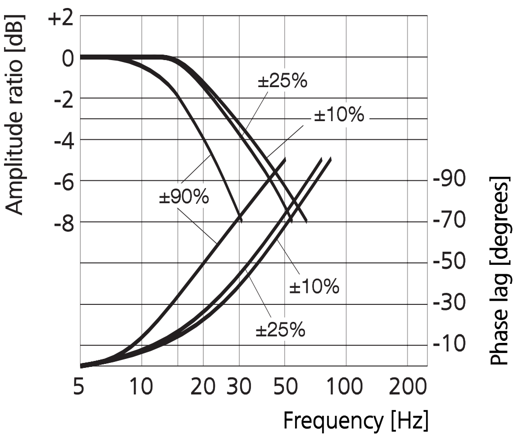
Step response



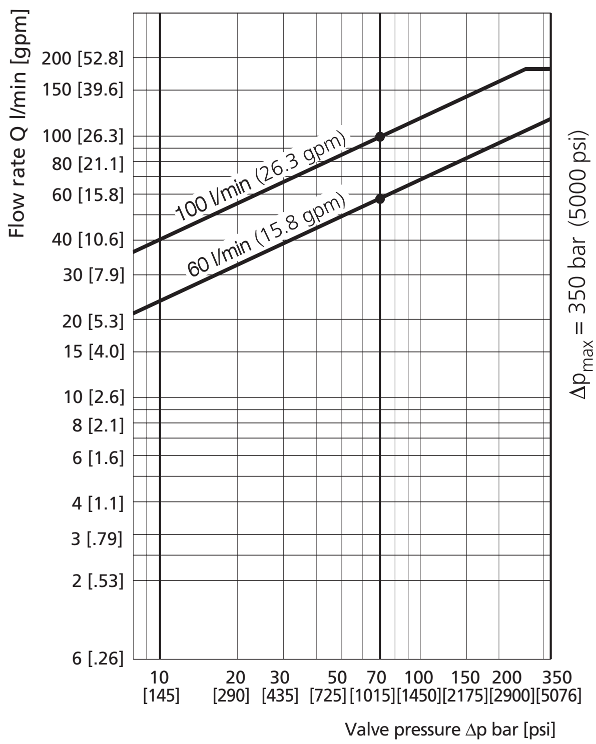
Flow signal characteristic curve



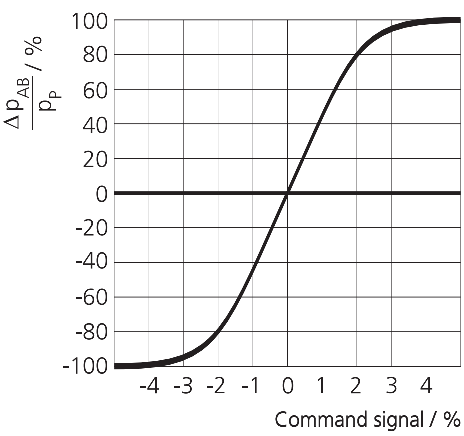
Frequency response



Valve flow diagram



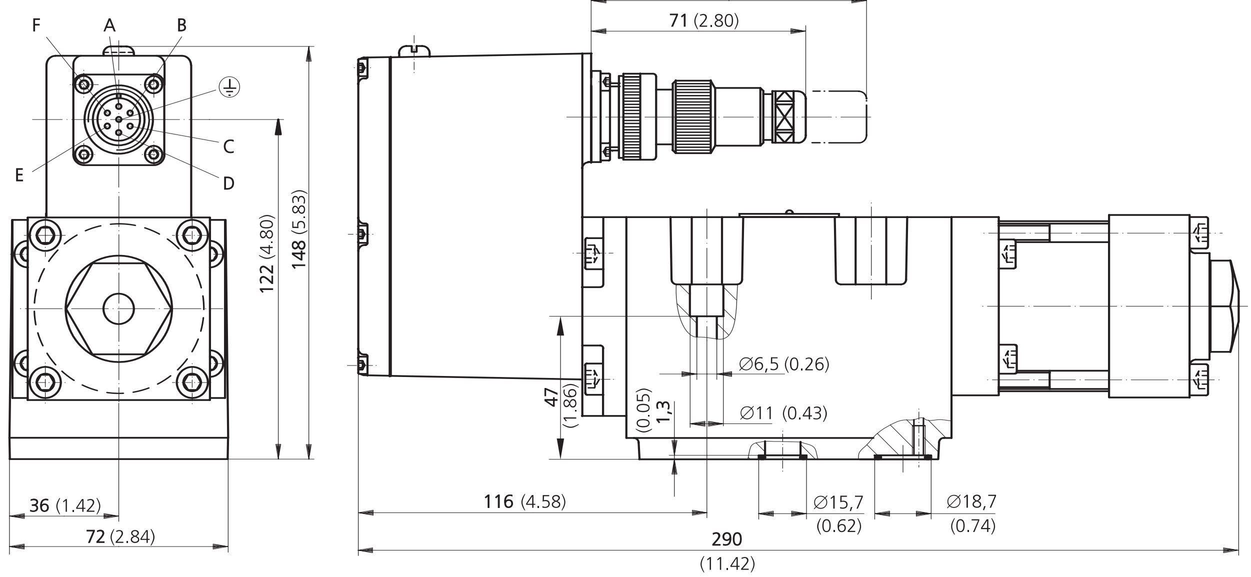
Pressure signal characteristic curve



TECHNICAL DATA

D634

INSTALLATION DRAWING



Mounting pattern

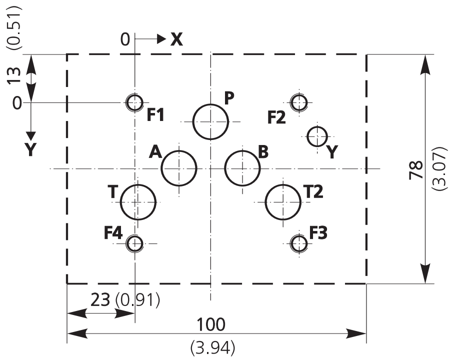
ISO 4401-05-05-0-94, without X port

mm

	P	A	B	T	T_2	X[1]	Y	F_1	F_2	F_3	F_4
	Ø11,2	Ø11,2	Ø11,2	Ø11,2	Ø11,2		Ø 6,3	M6	M6	M6	M6
x	27	16,7	37,3	3,2	50,8		62	0	54	54	0
y	6,3	21,4	21,4	32,5	32,5		11	0	0	46	46

inch

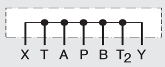
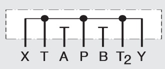
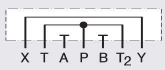
	P	A	B	T	T_2	X[1]	Y	F_1	F_2	F_3	F_4
	Ø0.44	Ø0.44	Ø0.44	Ø0.44	Ø0.44		Ø 0.25	M6	M6	M6	M6
x	1.06	0.66	1.47	0.13	2.00		2.44	0	2.13	2.13	0
y	0.25	0.84	0.84	1.28	1.28		0.43	0	0	1.81	1.81



[1]) Port X must not be drilled, not sealed at valve base.

Mounting surface needs flat within 0,01 mm (0.0004 in) over a distance of 100 mm (3.94 in). Average surface finish value, Ra = 0.8 µm.

Spare parts and Accessories

O-Rings (included in delivery) for ports P,T,T2,A,B for port Y	 5 pieces ID 12.4 x Ø 1.8 (ID 0.49 x Ø 0.07) 1 piece ID 15.6 x Ø 1.8 (ID 0.61 x Ø 0.07)		NBR 90 Shore 45122-004 45122-011	FPM 90 Shore 42082-004 42082-011
Mating connector, waterproof IP65 (not included in delivery) 6+PE-pole	 B97007 061	 EN 175201 Part 804	for cable dia	min. Ø 10 mm (0.394 in), max. Ø 12 mm (0.472 in)
Flushing plates	for P,A,B,T,T2,X,Y B67728 001			
Flushing plates	for P,A,B,T,T2,X,Y B67728 002			
Flushing plates	for P,A,B,T,T2,X,Y B67728 003			
Mounting manifolds	on request			
Mounting bolts (not included in delivery) M 6 x 60 DIN EN ISO 4762-10.9 A03665 060 060		required torque 13 Nm (115 inch pounds)	required 4 pieces	

ORDERING INFORMATION

D633-D634

ORDERING INFORMATION

Model-Number: D 63 . . . . . .

Type designation: . . . .

Series

3	Size 03
4	Size 05

Specification-Status

-	Series specification
E	Preseries specification
K	explosion proof version upon request
Z	Special specification

Model designation

	assigned at the factory

Factory identification

Valve version

R	with integrated electronics

Rated flow

	Q_N[l/min] at Δp_N = 35 bar (Q_N[gpm] at Δp_N = 500 psi)	Δp_N = 5 bar per land	Series
02	5 (1.3)	2	D633
04	10 (2.6)	4	D633
08	20 (5.3)	8	D633
16	40 (10.6)	16	D633
24	60 (15.8)	24	D634
40	100 (26.3)	40	D634

Maximum operating pressure

K	350 bar (5000 psi)

Options may increase price and delivery.
All combinations may not be available.
Preferred configurations are highlighted.
Technical changes are reserved.

Supply voltage

2	24 VDC (19 to 32 VDC)

Signals for 100% spool stroke*

	Command	Output
M	±10 VDC	+4 to +20 mA
X	±10 mA, floating	+4 to +20 mA
	deadband compensation on request	

Valve connector

S	6+PE pole EN 175201 Part 804

Seal material

N	NBR (Buna)
V	FPM (Viton)
	others on request

Y- port

0	closed with plug	p_{Tmax} = 50 bar (715 psi)
3	open, with filter insert	p > 50 bar (715 psi)

Spool position without electric supply

M	mid position
F	P ▸ B, A ▸ T connected (10% open)
D	P ▸ A, B ▸ T connected (10% open)
	other openings on request

Linear motor

		Series
1	Standard	D633
2	Standard	D634

Bushing / Spool type

0	4-way:	axis cut, linear characteristic
A	4-way:	1,5 to 3% overlap, linear characteristic
D	4-way:	10% overlap, linear characteristic
Z	2x2-way:	P ▸ A, B ▸ T, with Y-port only
X	Special spool on request	

*(input voltage limited, see page 6)

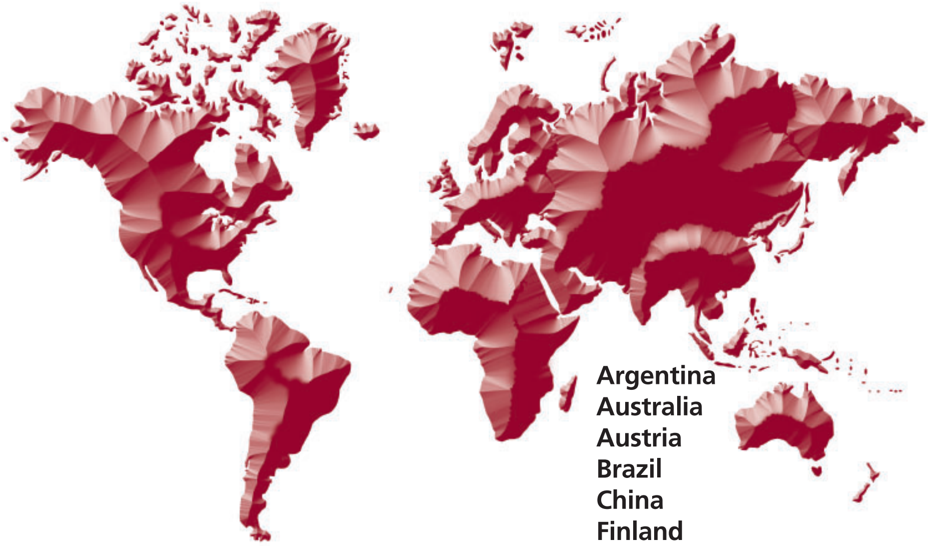
NOTES

D633-D634

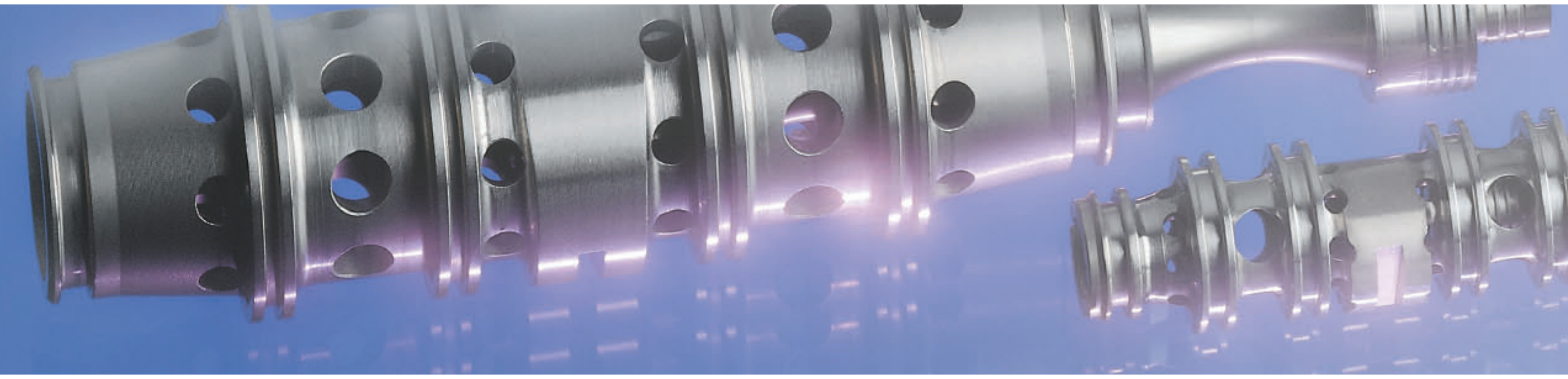
NOTES

D633-D634

-



Argentina
Australia
Austria
Brazil
China
Finland
France
Germany
India
Ireland
Italy
Japan



Korea
Luxembourg
Netherlands
Norway
Russia
Singapore
South Africa
Spain
Sweden
Switzerland
United Kingdom
USA

TJWhite / PDF

MOOG

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Germany: +49-7031-622-0
Japan: +81-463-55-3615
For the location nearest you, visit
www.moog.com/worldwide.

CDL6581 Rev H 500-189 1005

C.2 Mean Well DRP-240-24 PSU

MEAN WELL

240W Single Output Industrial DIN RAIL Power Supply **DRP-240 series**

■ Features :

- Universal AC input / Full range
- Built in active PFC function
- Protections: Short circuit / Overload / Over voltage / Over temperature
- Cooling by free air convection
- Can be installed on DIN rail TS-35/7.5 or 15
- UL 508(industrial control equipment)approved
- LED indicator for power on
- 100% full load burn-in test
- Fixed switching frequency at 100KHz
- 3 years warranty

SPECIFICATION

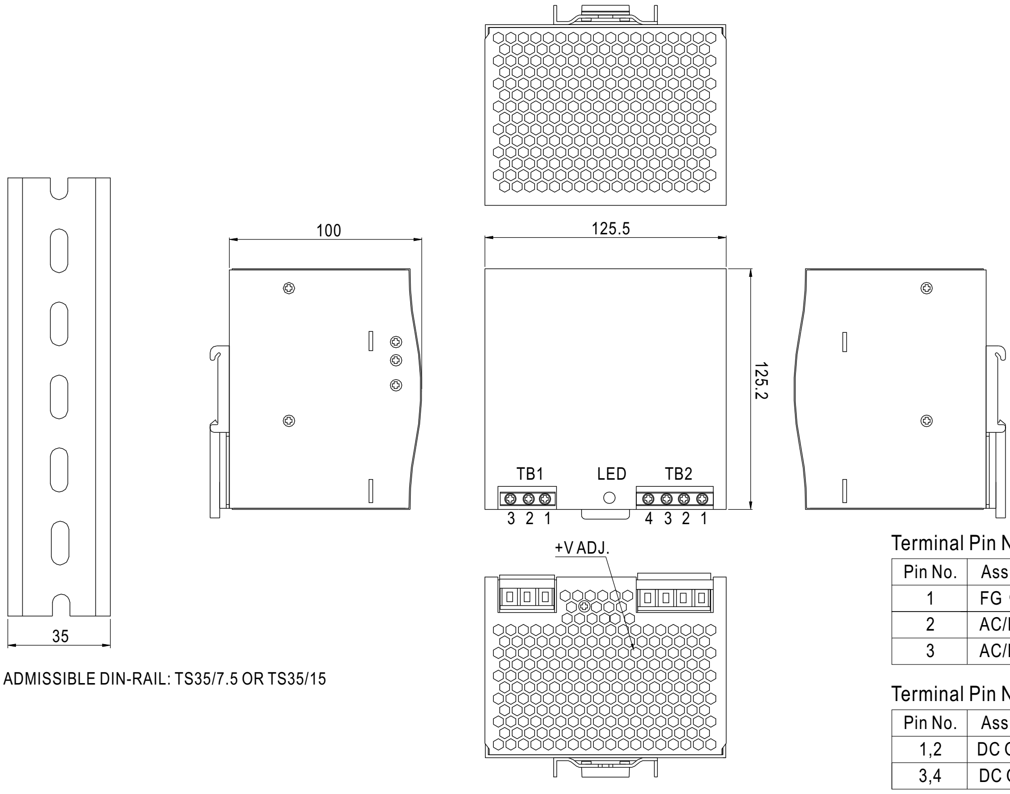
MODEL		DRP-240-24	DRP-240-48
OUTPUT	DC VOLTAGE	24V	48V
	RATED CURRENT	10A	5A
	CURRENT RANGE	0 ~ 10A	0 ~ 5A
	RATED POWER	240W	240W
	RIPPLE & NOISE (max.) Note.2	80mVp-p	150mVp-p
	VOLTAGE ADJ. RANGE	24 ~ 28V	48 ~ 53V
	VOLTAGE TOLERANCE Note.3	±1.0%	±1.0%
	LINE REGULATION	±0.5%	±0.5%
	LOAD REGULATION	±1.0%	±1.0%
	SETUP, RISE TIME	800ms, 40ms/230VAC 800ms, 40ms/115VAC at full load	
	HOLD UP TIME (Typ.)	24ms/230VAC 24ms/115VAC at full load	
INPUT	VOLTAGE RANGE Note.5	85 ~ 264VAC 120 ~ 370VDC	
	FREQUENCY RANGE	47 ~ 63Hz	
	POWER FACTOR (Typ.)	0.96/230VAC 0.99/115VAC at full load	
	EFFICIENCY (Typ.)	84%	85%
	AC CURRENT (Typ.)	2.8A/115VAC 1.4A/230VAC	
	INRUSH CURRENT (Typ.)	COLD START 27A/115VAC 45A/230VAC	
	LEAKAGE CURRENT	<3.5mA / 240VAC	
PROTECTION	OVERLOAD	105 ~ 150% rated output power	
		Protection type : Constant current limiting, recovers automatically after fault condition is removed	
	OVER VOLTAGE	30 ~ 36V	54 ~ 60V
		Protection type : Shut down o/p voltage, re-power on to recover	
	OVER TEMPERATURE	100℃±5℃ (TSW1)detect on heat sink of power transistor	
		Protection type : Shut down o/p voltage, recovers automatically after temperature goes down	
ENVIRONMENT	WORKING TEMP.	-10 ~ +70℃ (Refer to "Derating Curve")	
	WORKING HUMIDITY	20 ~ 90% RH non-condensing	
	STORAGE TEMP., HUMIDITY	-20 ~ +85℃, 10 ~ 95% RH	
	TEMP. COEFFICIENT	±0.03%/℃ (0 ~ 50℃)	
	VIBRATION	10 ~ 500Hz, 2G 10min./1cycle, 60min. each along X, Y, Z axes; Mounting: Compliance to IEC60068-2-6	
SAFETY & EMC (Note 4)	SAFETY STANDARDS	UL508, UL60950-1, TUV EN60950-1 approved	
	WITHSTAND VOLTAGE	I/P-O/P:3KVAC I/P-FG:1.5KVAC O/P-FG:0.5KVAC	
	ISOLATION RESISTANCE	I/P-O/P, I/P-FG, O/P-FG:100M Ohms/500VDC	
	EMC EMISSION	Compliance to EN55011,EN55022 (CISPR22) Class B, EN61000-3-2,-3	
	EMC IMMUNITY	Compliance to EN61000-4-2,3,4,5,6,8,11, EN55024, EN61000-6-2 (EN50082-2), heavy industry level, criteria A	
OTHERS	MTBF	289.9Khrs min. MIL-HDBK-217F (25℃)	
	DIMENSION	125.5*125.2*100mm (W*H*D)	
	PACKING	1.2Kg; 12pcs/15.5Kg/1.29CUFT	
NOTE	1. All parameters NOT specially mentioned are measured at 230VAC input, rated load and 25℃ of ambient temperature. 2. Ripple & noise are measured at 20MHz of bandwidth by using a 12" twisted pair-wire terminated with a 0.1uf & 47uf parallel capacitor. 3. Tolerance : includes set up tolerance, line regulation and load regulation. 4. The power supply is considered a component which will be installed into a final equipment. The final equipment must be re-confirmed that it still meets EMC directives. 5. Derating may be needed under low input voltages. Please check the derating curve for more details.		

MEAN WELL

240W Single Output Industrial DIN RAIL Power Supply **DRP-240 series**

Mechanical Specification

Case No. 922A Unit:mm



ADMISSIBLE DIN-RAIL: TS35/7.5 OR TS35/15

Terminal Pin Number Assignment (TB1)

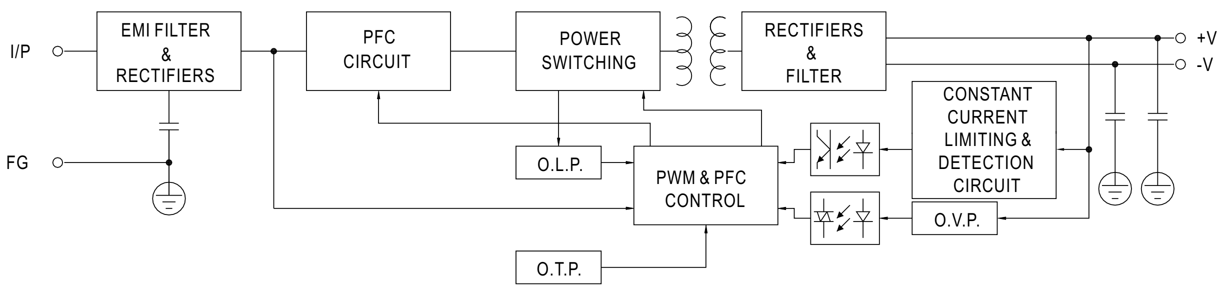
Pin No.	Assignment
1	FG ⏚
2	AC/N
3	AC/L

Terminal Pin Number Assignment (TB2)

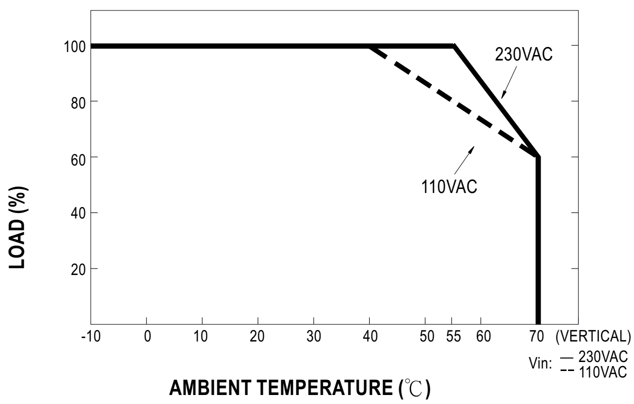
Pin No.	Assignment
1,2	DC OUTPUT +V
3,4	DC OUTPUT -V

Block Diagram

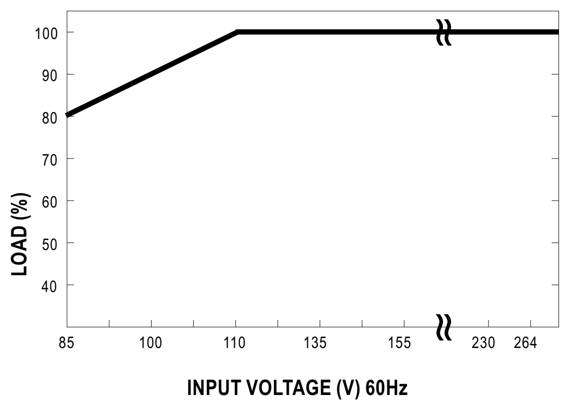
fosc : 100KHz



Derating Curve

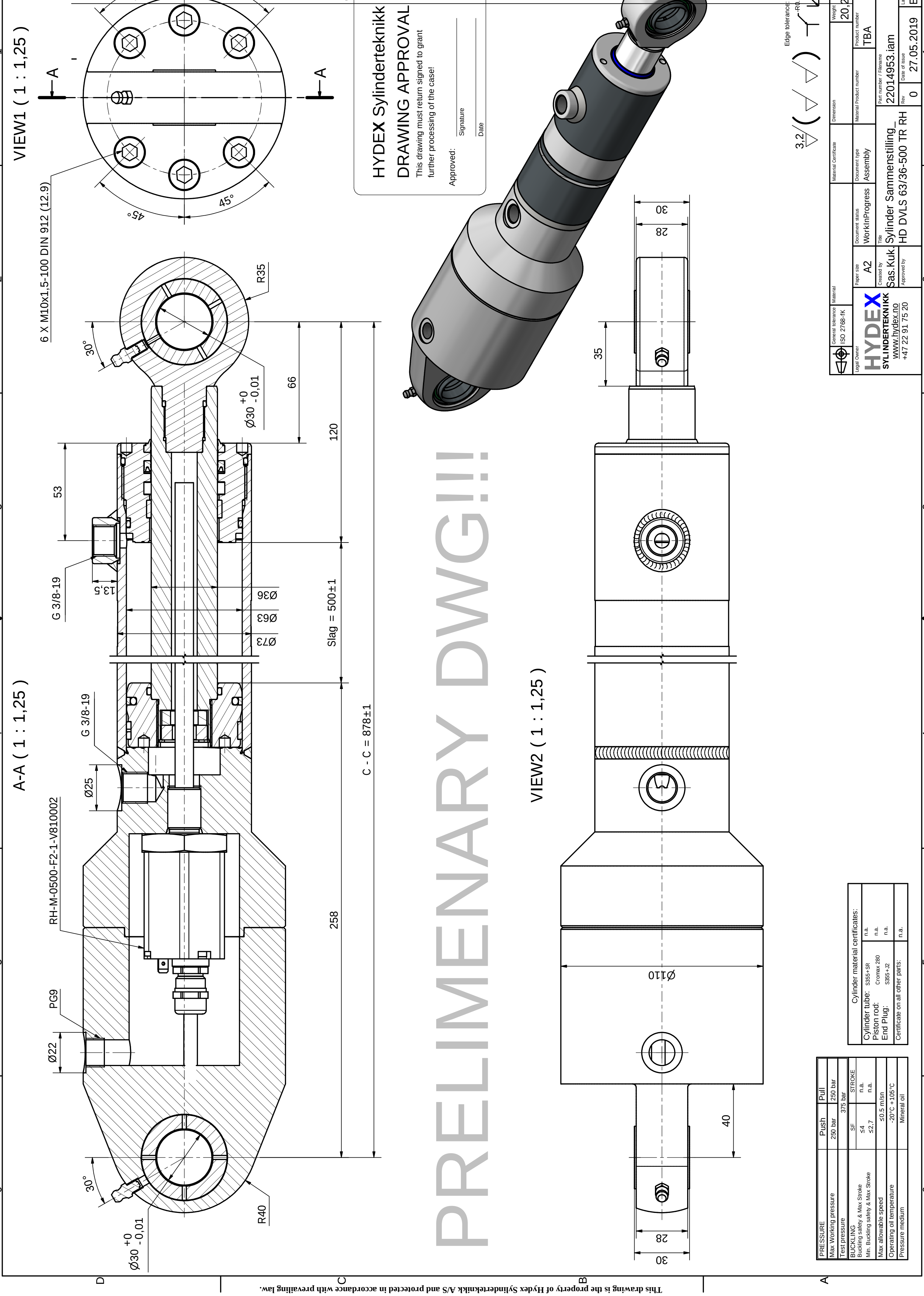


Output derating VS input voltage



C.3 Cylinder Technical Drawing

C.3. Cylinder Technical Drawing



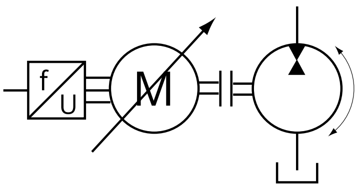
C.4 A10FZG Pump

Function and layout of variable-speed drives

Rexroth has further developed the proven axial piston units from the A10 product family for use in energy-efficient variable-speed drives and optimized the interplay between the electric motor and the pump. The especially robust units are employed for small to medium sizes and satisfy individual requirements with their numerous combination options.
Variable-speed pump drives featuring Rexroth technology reduce energy consumption in industrial applications, while also reducing noise emissions. At the same time, the familiar performance is retained or even improved. The extensive spectrum of different variable-speed pump drives from Rexroth includes ready-to-use solutions that are finely scalable in both function and power. The energy-efficient hydraulic drive can be realized with internal gear pumps, fixed or variable axial piston units. Equipped with a suitable controller, exactly the required flow and pressure are provided which are needed at the machine.
The proven axial piston units have been developed further for use in speed-controlled drives.

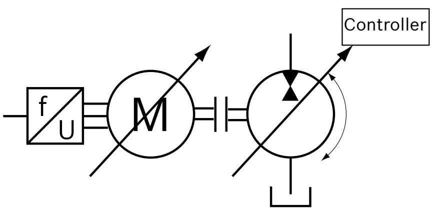
These are approved for start/stop operation and designed for a changing direction of rotation. Even at the lowest speeds, between 0 and 200 rpm, they provide a constant pressure and are characterized by very high efficiency in pressure holding operation. Efficiency is achieved optimized by either a fixed or variable displacement, depending on the requirements of the cycle. The A10 units can be used as pumps and as motors in one-, two- or four-quadrant operation.
For the implementation of variable-speed drives, the new axial piston units offer numerous options for combination. The axial piston fixed displacement units A10FZO and A10FZG cover the sizes 3 to 63 cm^3. The axial piston variable displacement units are available in the sizes 3 to 180 cm^3 (A10VZO) and 3 to 63 cm^3 (A10VZG). Equipped with a torque controller and 2-point control, they allow for a smaller dimensioning of the electric drive. The numerous combination options allow a wide range of different customized system requirements to be satisfied.

A10FZO



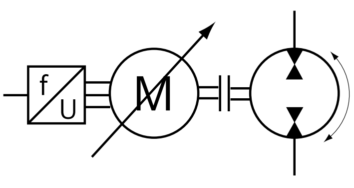
Axial piston fixed displacement units in open circuit with changing direction of rotation and unchanging pressure side (depends on the principal direction of rotation of the pump).
one- or two-quadrant operation
For type codes, see page 6
For technical data, see page 10 and 11

A10VZO



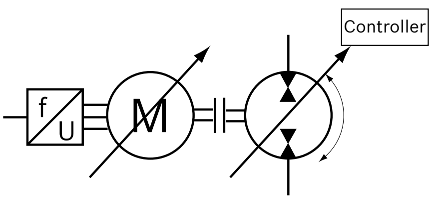
Axial piston variable displacement units in open circuit with changing direction of rotation and unchanging pressure side (depends on the principal direction of rotation of the pump).
one- or two-quadrant operation
For type codes, see page 24 and 25
For technical data, see page 31

A10FZG



Axial piston fixed displacement unit in closed circuit with changing direction of rotation and two pressure sides.
One-, two- and four-quadrant operation
For type codes, see page 62
For technical data, see page 66 and 67

A10VZG



Axial piston variable displacement unit in closed circuit with changing direction of rotation and two pressure sides.
One-, two- and four-quadrant operation
For type codes, see page 78
For technical data, see page 82

Hydraulic fluids

The fixed displacement units A10FZO and A10FZG and variable displacement units A10VZO and VZG are designed for operation with HLP mineral oil according to DIN 51524. Application instructions and requirements for hydraulic fluids should be taken from the following data sheets before the start of project planning:

- 90220: Hydraulic fluids based on mineral oils and related hydrocarbons

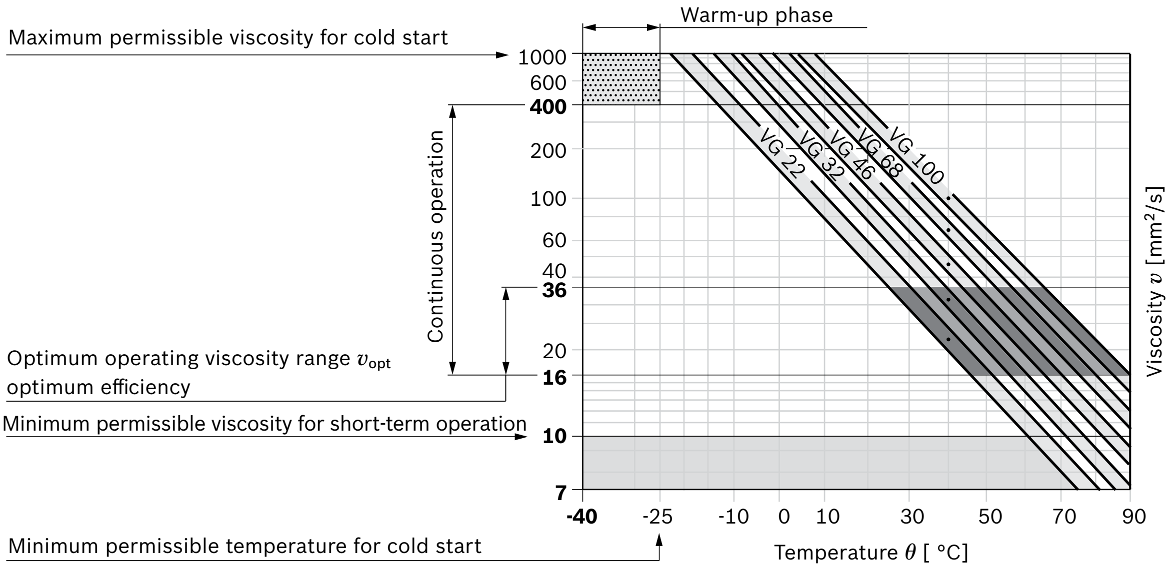
Notes on selection of hydraulic fluid
The hydraulic fluid should be selected so that the operating viscosity in the operating temperature range is within the optimum range (ν_{opt} see selection diagram).

Note
At no point of the component may the temperature be higher than 90 °C. The temperature difference specified in the table is to be taken into account when determining the viscosity in the bearing.
If the above conditions cannot be maintained due to extreme operating parameters, please contact the responsible member of staff at Bosch Rexroth.

Viscosity and temperature of hydraulic fluids

	Viscosity	Temperature	Comment
Cold start	$\nu_{max} \leq 1000$ mm²/s	$\theta_{St} \geq -25$ °C	$t \leq 3$ min, without load ($p \leq 30$ bar), $n \leq 1000$ rpm
Permissible temperature difference		$\Delta T \leq 13$ K	between axial piston unit and hydraulic fluid
Warm-up phase	ν < 1000 to 400 mm²/s	$\theta = \leq -25$ °C	Note the detailed information on operation with low temperatures, see data sheet 90300-03-B.
Continuous operation	ν = 400 to 16 mm²/s		This corresponds, for example on the VG 46, to a temperature range of +5 °C to +70 °C (see selection diagram page 3)
		θ = -25 °C to +85 °C	measured at port **L** Observe the permissible temperature range of the shaft seal (ΔT = approx. 5 K between the bearing/shaft seal and port **L**)
	ν_{opt} = 36 to 16 mm²/s		Range of optimum operating viscosity and efficiency
Short-term operation	ν_{min} 10 to 16 mm²/s		$t < 3$ min, $p < 0.3 \cdot p_{nom}$

▼ **Selection diagram**



Filtration of the hydraulic fluid

Finer filtration improves the cleanliness level of the hydraulic fluid, which increases the service life of the axial piston unit. A cleanliness level of at least 20/18/15 is to be maintained according to ISO 4406.

Axial piston fixed displacement unit A10FZG

- For variable-speed operation with synchronous and asynchronous motors
- Sizes 3 to 63
- Nominal pressure/maximum pressure 315/350 bar
- Open and closed circuits

Features

- For use in one-, two- or four-quadrant operation
- Suitable for start/stop operation
- Suitable for long pressure holding operation
- Proven A10 rotary group technology
- Through drive option

Product description

The proven axial piston units from the A10 product family have now been further developed for use in speed-controlled drives. They are approved for start/stop operation and designed for a changing direction of rotation. Even at the lowest speed between 0 and 200 rpm, they provide a constant pressure and offer extremely high efficiency in pressure holding operation. The A10FZG units can be used as a pump in one, two and four-quadrant operation.

Type code A10FZG

01	02	03	04		05	06		07	08	09	10	11
A10F	**Z**	**G**		**/**	**10**	**W**	**–**	**V**		**C**	**02**	

Axial piston unit

01	Swashplate design, fixed, nominal pressure 315 bar, maximum pressure 350 bar	**A10F**

Application area

02	Variable-speed drives	**Z**

Operating mode

03	Pump, open and closed circuit	**G**

Size Geometric displacement, see table of values on page 66 and 67

04		**010**	**018**	**028**	**045**	**063**
	Other available intermediate sizes	003, 006, 008	012, 014, 016	021, 022, 023, 025, 026, 027	032, 035, 037, 039, 040, 041, 042	051, 058

Series

05	Series 1, index 0	**10**

Direction of rotation

06	Viewed on drive shaft	changing	**W**

Sealing material

07	FKM (fluoroelastomer)	**V**

Drive shaft

08	Splined shaft ANSI B92.1a	Standard shaft	●	–	–	–	–	**S**
		similar to shaft "S" however for higher torque	–	●	●	○	○	**R**

Mounting flange

09	ISO 3019-1 (SAE)	**C**

Working port

10	SAE flange ports **A** and **B**, opposite sides, metric fastening thread	**02**

Through drive (for mounting options, see page 100)

11	Flange ISO 3019-1 Diameter	Hub for splined shaft[1)] Diameter		**010**	**018**	**028**	**045**	**063**	
	without through drive			●	●	●	○	○	**N00**
	82-2 (A)	5/8 in	9T 16/32DP	●	●	●	○	○	**K01**
		3/4 in	11T 16/32DP	●	●	●	○	○	**K52**
	101-2 (B)	7/8 in	13T 16/32DP	–	–	●	○	○	**K68**
		1 in	15T 16/32DP	–	–	–	○	○	**K04**
		1 1/4 in	14T 12/24DP	–	–	–	–	○	**K06**

● = Available ○ = On request – = Not available

Notice

- Note the project planning notes on page 105.
- In addition to the type code, please specify the relevant technical data when placing your order.

1) Splined shaft according to ANSI B92.1a (splined shafts according to SAE J744)

Preferred program A10FZG

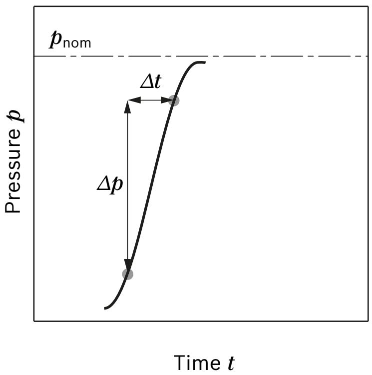
Overview of common configurations

Type	Material number
A A10FZG003/10W-VSC02N00	R902544378
A A10FZG006/10W-VSC02N00	R902544475
A A10FZG008/10W-VSC02N00	R902544393
A A10FZG010/10W-VSC02N00	R902544389
A A10FZG012/10W-VRC02N00	R902530960
A A10FZG014/10W-VRC02N00	R902530961
A A10FZG016/10W-VRC02N00	R902530962
A A10FZG018/10W-VRC02N00	R902530963
A A10FZG021/10W-VRC02N00	R902536290
A A10FZG022/10W-VRC02N00	R902557896
A A10FZG023/10W-VRC02N00	R902557897
A A10FZG025/10W-VRC02N00	R902557898
A A10FZG026/10W-VRC02N00	R902557899
A A10FZG027/10W-VRC02N00	R902557900
A A10FZG028/10W-VRC02N00	R902534818

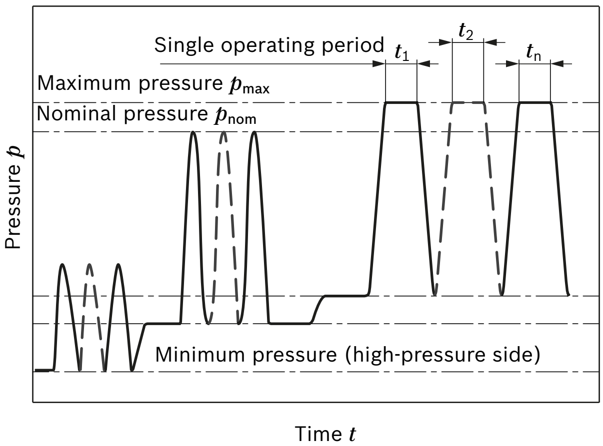
Working pressure range A10FZG

Pressure at working port B or A		**Definition**
Nominal pressure p_{nom}	315 bar absolute	The nominal pressure corresponds to the maximum design pressure.
Maximum pressure p_{max}	350 bar absolute	The maximum pressure corresponds to the maximum working pressure within the single operating period. The sum of the single operating periods must not exceed the total operating period.
Single operating period	2.0 ms	
Total operating period	300 h	
Rate of pressure change $R_{A\ max}$	16000 bar/s	Maximum permissible speed of pressure build-up and reduction during a pressure change across the entire pressure range.
Pressure at port A or B (low-pressure side)		
Minimum pressure p_{min} Standard	0.8 bar absolute	Minimum pressure on the low-pressure side that is required in order to prevent damage to the axial piston unit. The minimum pressure depends on the rotational speed and displacement of the axial piston unit.
Summation pressure		
		The sum of the pressures on ports **A** and **B** must not rise above 400 bar.
Case pressure at port L		
Maximum pressure $p_{L\ max}$	2 bar absolute[1]	Maximum 0.5 bar higher than inlet pressure at low-pressure port, but not higher than $p_{L\ max}$. A drain line to the reservoir is required.

▼ **Rate of pressure change $R_{A\ max}$**



▼ **Pressure definition**



Total operating period = $t_1 + t_2 + ... + t_n$

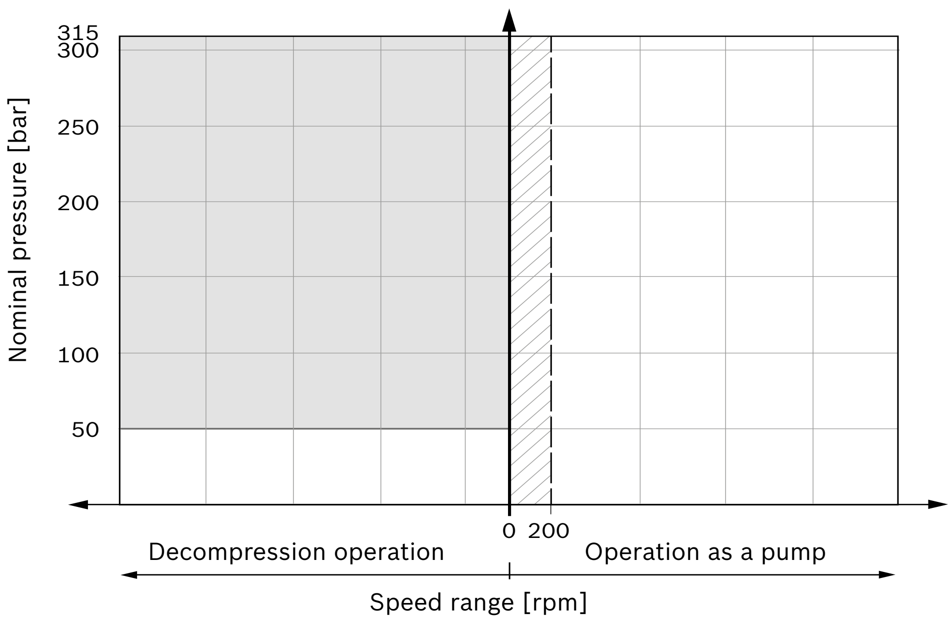
Notice
Working pressure range valid when using hydraulic fluids based on mineral oils. Please contact us for values for other hydraulic fluids.

Flow direction

Direction of rotation, viewed on drive shaft	**Direction of rotation**	**Flow**
Type code "**W**"	Clockwise	**A** to **B**
	Counterclockwise	**B** to **A**

1) Higher values on request

A10FZG: Permissible operating data and operating ranges at $V_{g\ max}$



Operating range	
☐	Operation without restriction
▨	Permissible with single operating period t ≤ 3 min; maximum cycle share 80%. For longer time periods t > 3 min, please use A10VZG.
▩	Operation as a motor possible with restrictions, please contact us. Permissible for short-term decompression operation t ≤ 200 ms

Technical data A10FZG size 3 to 63

Superordinate size		**NG**		**10**				**18**				**28**			
Available intermediate sizes		**NG**		**3**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**21**	**22**	**23**	**25**
Displacement, geometric, per revolution		$V_{g\,max}$	cm^3	3	6	8.1	10.6	12	14	16	18	21	22	23	25
Rotational speed maximum[1]	at $V_{g\,max}$														
Suction speed operation as a pump[1]		n_{nom}	rpm	3600				3300				3000			
Max. speed decompression operation[2]		n_{nom}	rpm	3600				3300				3000			
Flow	at n_{nom} and $V_{g\,max}$	q_v	l/min	10.8	21.6	29	38.2	39.6	46.2	52.8	59.4	63	66	69	75
Power pump operation	at n_{nom}, $V_{g\,max}$ and Δp = 315 bar	P	kW	5.6	11.3	15.3	20	21	24.2	27.7	31.2	33	34	36.3	39
Torque	at $V_{g\,max}$ and Δp = 315 bar	T	Nm	15	30	40.5	53	60.2	70.2	80.2	90.3	105	110	116	125
	at $V_{g\,max}$ and Δp = 100 bar	T	Nm	5	9.5	12.7	16.8	19.1	22.3	25.5	28.7	33.4	35	36.6	40
Rotary stiffness of drive shaft	S	c	Nm/rad	9200				–				–			
	R	c	Nm/rad	–				14800				26300			
Moment of inertia for rotary group		J_{TW}	kgm^2	0.0006				0.0009				0.0017			
Maximum angular acceleration[2][3]		α	rad/s^2	14000				12600				11200			
Case volume		V	l	0.11				0.19				0.6			
Weight (approx.)		m	kg	9				10				15.5			

Determining the characteristics		
Flow	$q_v = \dfrac{V_g \times n \times \eta_v}{1000}$	[l/min]
Torque	$T = \dfrac{V_g \times \Delta p}{20 \times \pi \times \eta_{hm}}$	[Nm]
Power	$P = \dfrac{2\,\pi \times T \times n}{60000} = \dfrac{q_v \times \Delta p}{600 \times \eta_t}$	[kW]

Key

V_g Displacement per revolution [cm^3]
Δp Differential pressure [bar]
n Rotational speed [rpm]
η_v Volumetric efficiency
η_{hm} Hydraulic-mechanical efficiency
η_t Total efficiency ($\eta_t = \eta_v \times \eta_{hm}$)

Notice

- Theoretical values, without efficiency and tolerances; values rounded
- Operation above the maximum values or below the minimum values may result in a loss of function, a reduced service life or in the destruction of the axial piston unit. We recommend testing the loads by means of experiment or calculation / simulation and comparison with the permissible values.

1) The values are applicable:
   – At absolute pressure $p_{abs} \geqq$ 1 bar on the low-pressure side (input)
   – For the optimal viscosity range of ν_{opt} = 36 to 16 mm^2/s
   – For hydraulic fluid based on mineral oils
2) Higher values on request
3) The limit value is only valid for a single pump, multiple pump version available on request. The load capacity of the connecting parts must be considered.

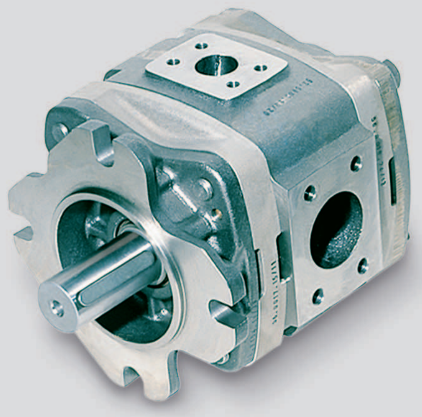
			45								63		
26	**27**	**28**	**32**	**35**	**37**	**39**	**40**	**41**	**42**	**45**	**51**	**58**	**63**
26	27	28	32	35	37	39	40	41	42	45	51	58	63
3000													
3000			On request										
78	81	84											
41	42	44											
130.4	135	140.4	160	175	185.6	195	200	206	210	225.7	256	291	316
41.4	43	44.6	51	56	59	62	64	65	67	71.6	81	92	100
–			–								–		
26300			41000								69400		
0.0017			0.003								0.0056		
11200			9500								On request		
0.6			0.7										
15.5			21										

C.5 IPVP Pump

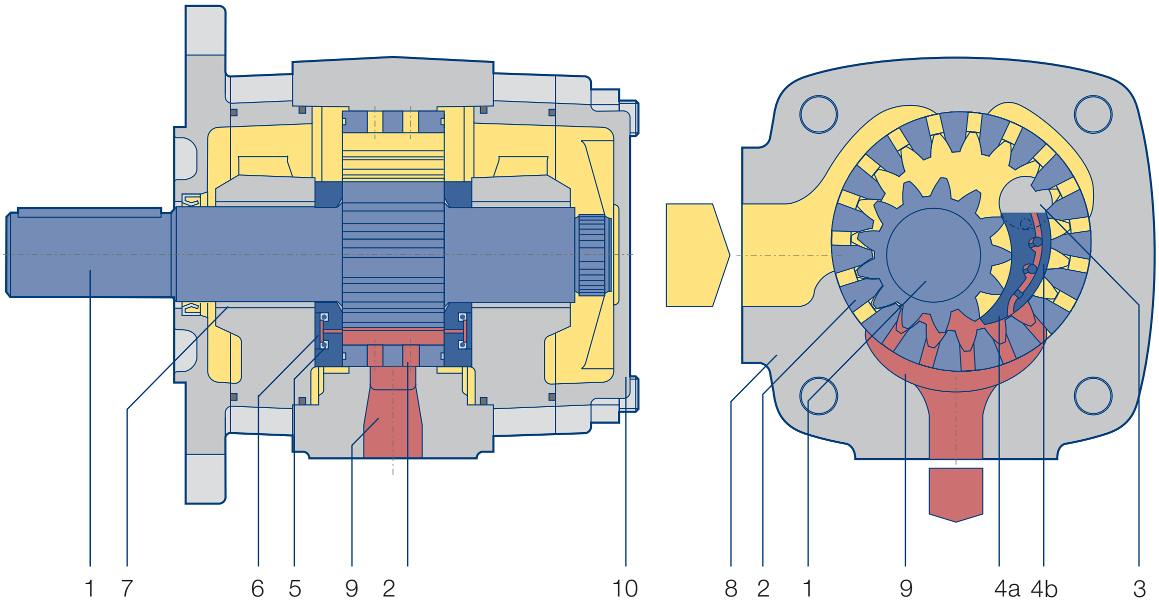
VOITH

IPVP High-pressure Internal Gear Pumps for Variable Speed Drives

Technical Data Sheet



Design and Function



1 Pinion shaft
2 Internal gear
3 Filler pin
4a Filler segment carrier
4b Filler sealing segment
5 Axial disc
6 Axial pressure area
7 Plain bearings
8 Housing
9 Hydrostatic bearing
10 End cover

Suction chamber
Pressure chamber

Function

By rotation of the gears inside the pump, the pressure fluid (usually hydraulic oil) is drawn into the cavity between the pinion and internal gear. Optimized cross-sectional areas on suction side as well as on pressure side allow operation over a wide range of speed.

In radial direction, the gear chambers are closed by gear meshing and the filler piece. In the axial direction, the axial plates seal the pressure chamber with the minimal possible gap. This design minimizes volume losses and increases efficiency.

Technical Data

Design	Internal gear pump with radial and axial sealing gap compensation
Type	IPVP
Mounting types	SAE hole flange; ISO 3019/1
Line mounting	SAE suction and pressure flange J 518 C Code 61
Sense of rotation	Right hand rotation
Mounting position	any
Shaft load	For details of radial and axial drive shaft loads please contact your Voith Turbo H + L Hydraulic representative
Input pressure	0.8…3 bar absolute pressure (at start up for short time 0.6 bar)
Pressure fluid	HLP mineral oils DIN 51524, part 2 or 3
Viscosity range of the pressure fluid	10…300 mm^2s-1 (cSt)), up to n=1800 min^{-1} 10 ... 100 mm^2s^{-1} (cSt), up to n_{max}
Permissible start viscosity	max. 2 000 mm^2s^{-1} (cSt)
Permissible temperature of the pressure fluid	-20 ... +80 °C
Required purity of the pressure fluid according to NAS 1638	Class 19 / 17 / 14 (ISO 4406), Class 8 (NAS 1638)
Filtration	Filtration quotient min. $\beta_{20} \geq 75$, recommended $\beta_{10} \geq 100$ (longer life)
Permissible ambient temperature	-20 ... +60 °C

Calculations

Pump flow	$Q = V_{g\,th} \cdot n \cdot \eta_v \cdot 10^{-3}$ [l / min]
Power	$P = \dfrac{Q \cdot \Delta p}{600 \cdot \eta_g}$ [kW]
$V_{g\,th}$	Pump volume per revolution [cm^3]
n	Speed [min^{-1}]
η_v	Volumetric efficiency
η_g	Overall efficiency
Δp	Differential pressure [bar]

Characteristics

Type, size – delivery	Displace-ment per revolution	Speed		Delivery		Pressures		
		min.	max.	at 1500 min^{-1}	at n_{max}	Continuous pressure	Peak pressure at 1 500 min^{-1}	Moment of inertia
	[cm^3]	[min^{-1}]	[min^{-1}]	[l/min]	[l/min]	[bar]	[bar]	[kg cm^2]
IPVP 3 – 3.5	3.6	400	3 600	5.4	13.0	330	345	0.34
IPVP 3 – 5	5.2	400	3 600	7.8	18.7	330	345	0.42
IPVP 3 – 6.3	6.4	400	3 600	9.6	23.0	330	345	0.49
IPVP 3 – 8	8.2	400	3 600	12.3	29.5	330	345	0.58
IPVP 3 – 10	10.2	400	3 600	15.3	36.7	330	345	0.70
IPVP 4 – 13	13.3	400	3 600	19.9	47.9	330	345	2.25
IPVP 4 – 16	15.8	400	3 600	23.7	56.9	330	345	2.64
IPVP 4 – 20	20.7	400	3 600	31.0	74.5	330	345	3.29
IPVP 4 – 25	25.4	400	3 600	38.1	91.4	300	330	3.70
IPVP 4 – 32	32.6	400	3 600	48.9	117.4	250	280	4.44
IPVP 5 – 32	33.1	400	3 000	49.6	99.3	315	345	8.62
IPVP 5 – 40	41.0	400	3 000	61.5	123.0	315	345	10.20
IPVP 5 – 50	50.3	400	3 000	75.4	150.9	280	315	11.60
IPVP 5 – 64	64.9	400	3 000	97.3	194.7	230	250	14.40
IPVP 6 – 64	64.1	400	2 600	96.1	166.7	300	330	25.73
IPVP 6 – 80	80.7	400	2 600	121.0	209.8	280	315	30.90
IPVP 6 – 100	101.3	400	2 600	151.9	263.4	250	300	36.10
IPVP 6 – 125	126.2	400	2 600	189.3	328.1	210	250	43.70
IPVP 7 – 125	125.8	400	2 500	188.7	314.5	300	330	84.05
IPVP 7 – 160	160.8	400	2 500	241.2	402.0	280	315	102.60
IPVP 7 – 200	202.7	400	2 500	304.0	503.8	250	300	119.00
IPVP 7 – 250	251.7	400	2 500	377.5	629.3	210	250	144.50

The values given apply for:

- Pumping of mineral oils with a viscosity of 20…40 mm^2s-1
- An input pressure of 0.8…3.0 bar absolute

Notes:

- Peak pressures apply for 15% of operating time with a maximum cycle time of 1 minute.
- Please inquire about peak pressures at non-standard speeds.
- Due to production tolerances, the pump volume may be reduced by up to 1.5%.
- The maximum speed depends on the pressure.
- **The speed range 0-400 min^{-1} depends on the pressure.** Please find data on the diagrams on the following pages.

Diagram IPVP 3, IPVP 4 - Continuous pressure depending on the speed

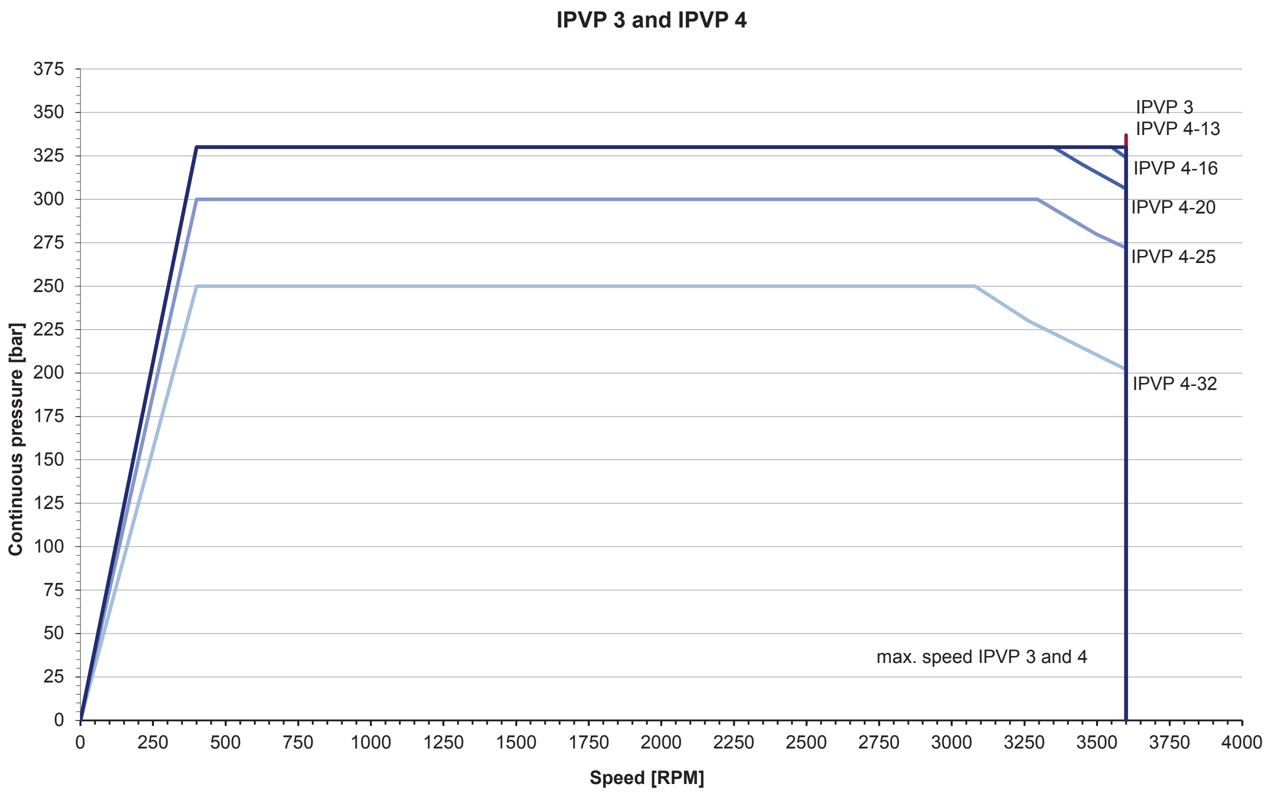
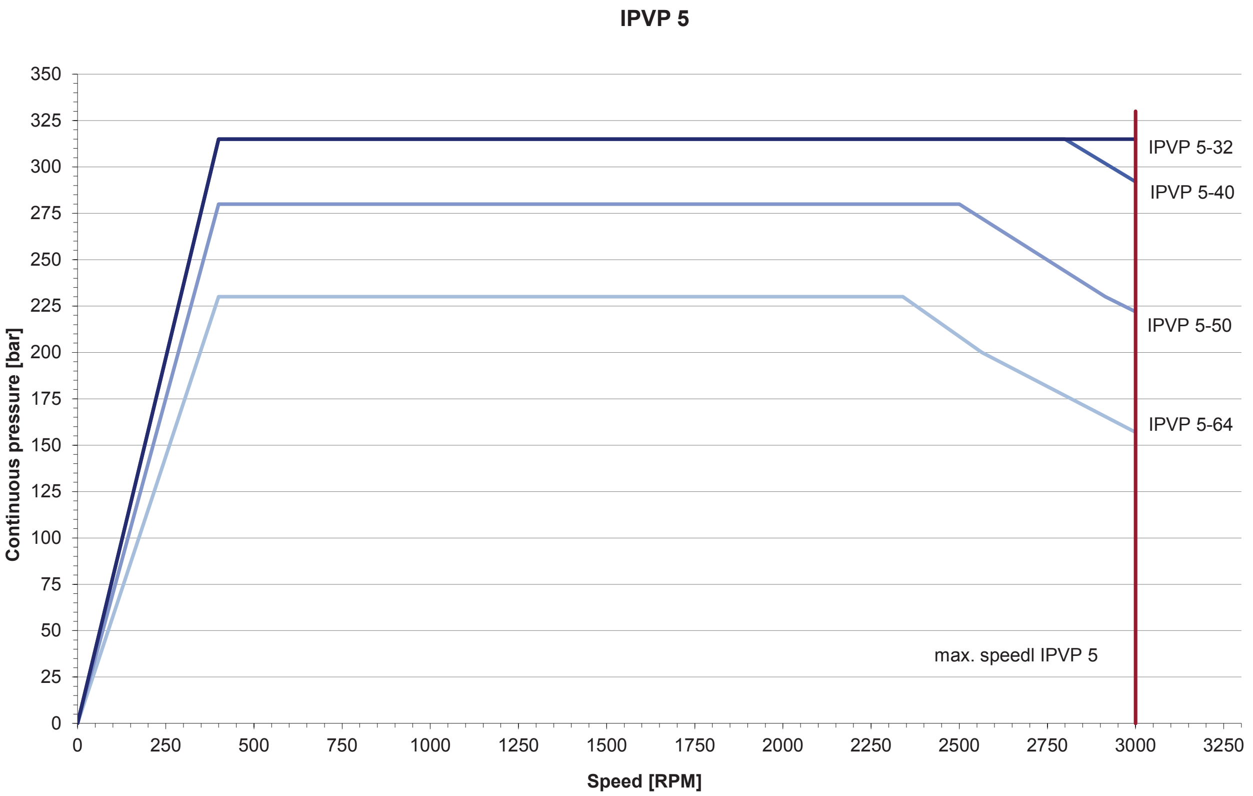
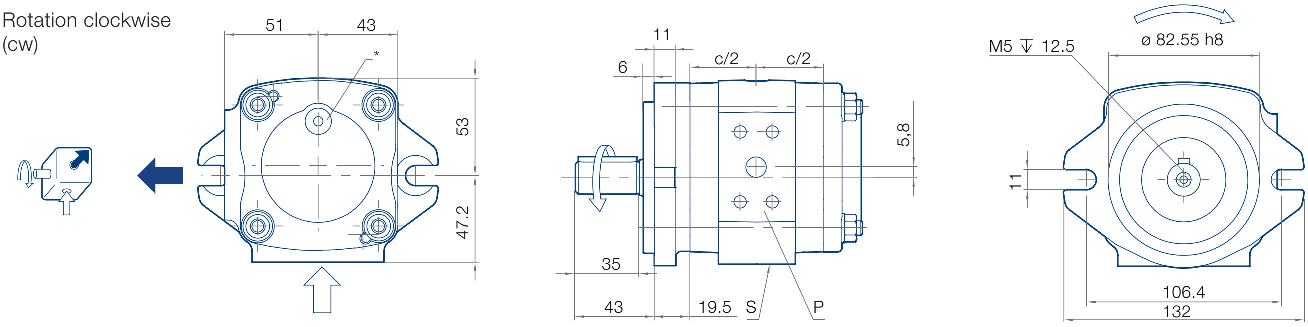


Diagram IPVP 5 - Continuous pressure depending on the speed

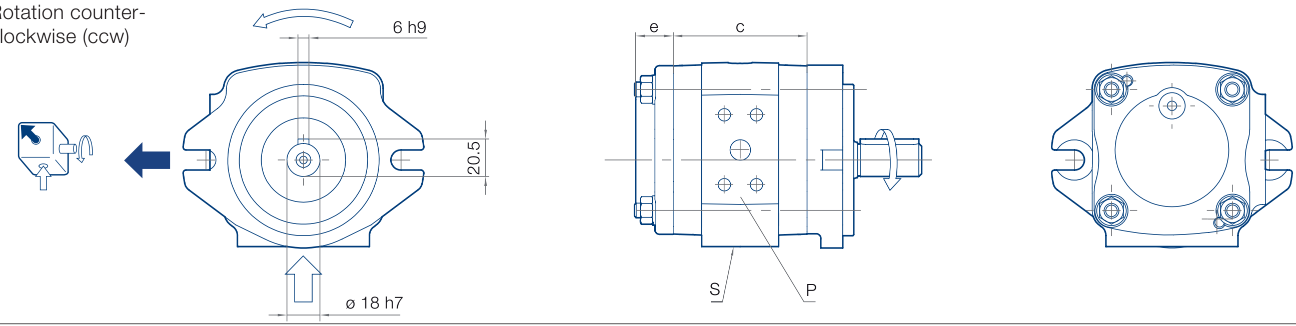


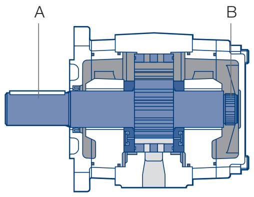
IPVP Size 3, Rotation and Dimensions

Rotation clockwise (cw)



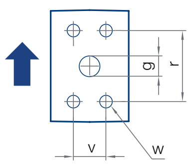
Rotation counter-clockwise (ccw)



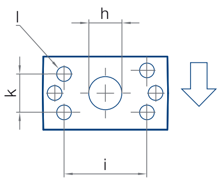


Allowed input torques:
Input shaft A: 160 Nm
Secondary shaft B: 80 Nm

Pressure port (P)



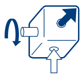
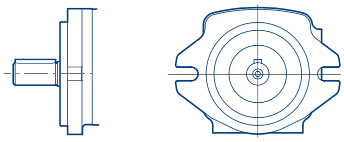
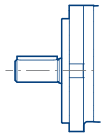
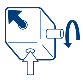
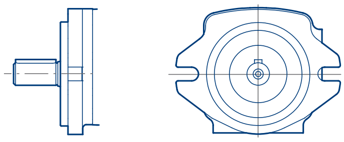
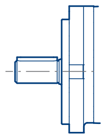
Suction port (S)



Type / Delivery	Dimensions and Weight											SAE Flange No.	
	c	e	g	h	i	k	l	r	v	w	Weight	↑ (pressure)	↓ (suction)
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	Thread	[mm]	[mm]	Thread	[kg]		
IPVP 3 – 3.5	66	20.5	9	14	38.1	17.5	M8 x 13	38.1	17.5	M8 x 13	4.2	10	10
IPVP 3 – 5	70	20.5	11	14	38.1	17.5	M8 x 13	38.1	17.5	M8 x 13	4.4	10	10
IPVP 3 – 6.3	73	20.5	11	19	47.6	22.3	M10 x 15	38.1	17.5	M8 x 13	4.6	10	11
IPVP 3 – 8	77.5	20.5	13	19	47.6	22.3	M10 x 15	38.1	17.5	M8 x 13	4.8	10	11
IPVP 3 – 10	82.5	20.5	13	21	52.4	26.2	M10 x 15	38.1	17.5	M8 x 13	5.0	10	12

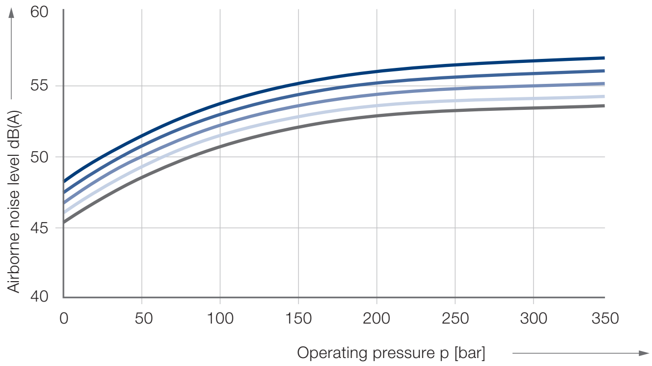
* Ensure the M10x1 plug screw, hexagon socket SW5, is tightened to a torque of 10 Nm during pumping operation. Dependent on the pump position, filling or ventilation is possible here prior to commissioning.

IPVP Size 3, Designs and Dimensions

Rotation, Suction port	Mounting flange	Shaft end
Standard		
Rotation clockwise, Suction connection  1	SAE 2-hole flange  0	Parallel shaft with keyway connection  1
Variants		
Rotation counterclockwise, Suction connection  6	SAE 2-hole flange  0	Parallel shaft with keyway connection  1

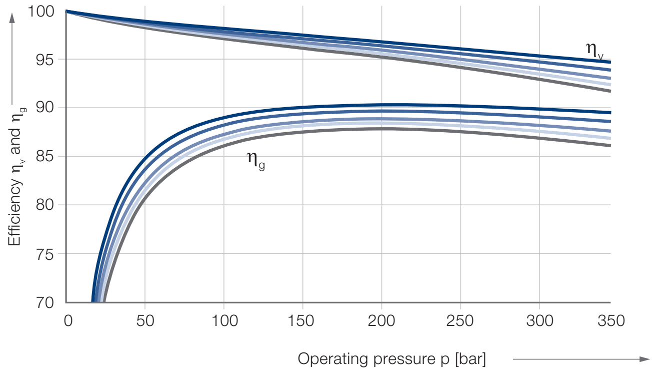
Measurement Values - Airborne Noise Level, Efficiency

IPVP 3 – Airborne noise level (measuring location 1 m axial)

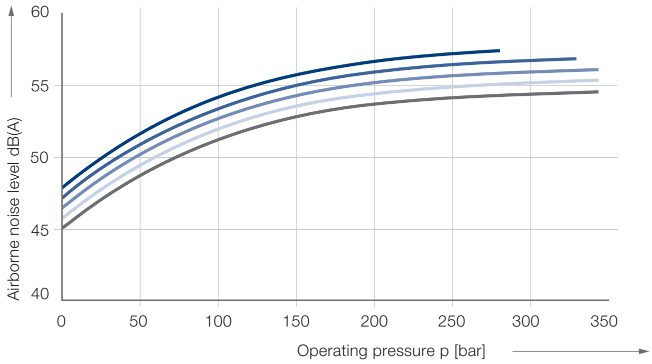


Characteristic curves:
IPVP 3 – 10 IPVP 3 – 8 IPVP 3 – 6.3 IPVP 3 – 5 IPVP 3 – 3.5

IPVP 3 – Efficiency η_v and η_g

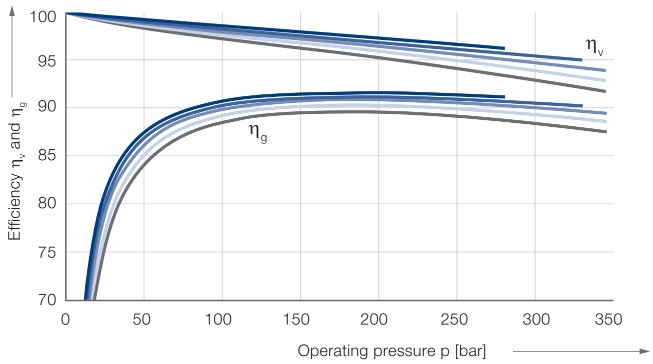


IPVP 4 – Airborne noise level (measuring location 1 m axial)

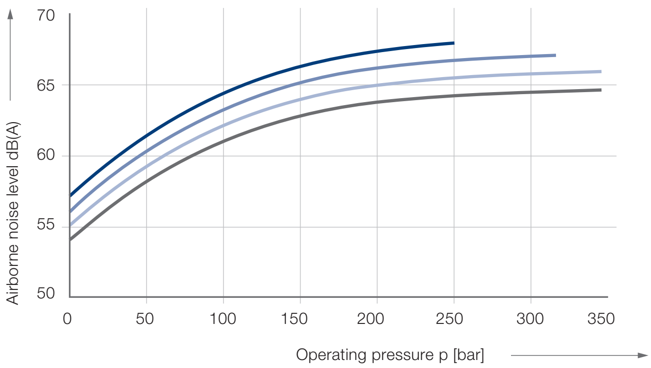


Characteristic curves:
IPVP 4 – 32 IPVP 4 – 25 IPVP 4 – 20 IPVP 4 – 16 IPVP 4 – 13

IPVP 4 – Efficiency η_v and η_g

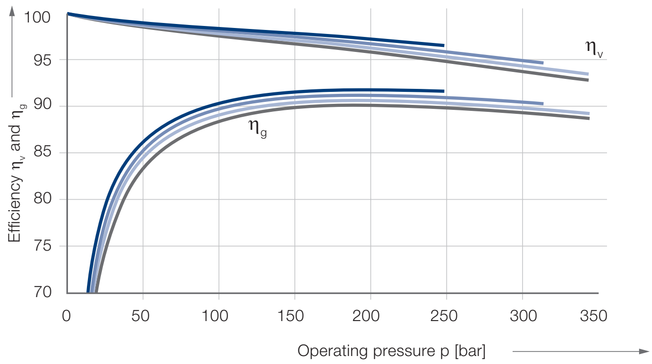


IPVP 5 – Airborne noise level (measuring location 1 m axial)



Characteristic curves:
IPVP 5 – 64 IPVP 5 – 50 IPVP 5 – 40 IPVP 5 – 32

IPVP 5 – Efficiency η_v and η_g



Type Code

IPVP 3 - 3.5 1 0 1

Shaft end
1 Parallel shaft with keyway

Mounting flange
0 SAE 2-hole
1 SAE 4-hole
7 SAE 2-hole, variant

Rotation, suction port
1 Clockwise rotation, radial suction port radial
6 Counterclockwise rotation, radial suction port radial
4 Clockwise rotation, special design
9 Counterclockwise rotation, special design

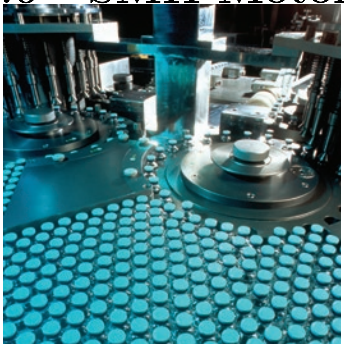
Delivery

Size	Delivery				
3	3.5	5	6.3	8	10
4	13	16	20	25	32
5	32	40	50	64	
6	64	80	100	125	
7	125	160	200	250	

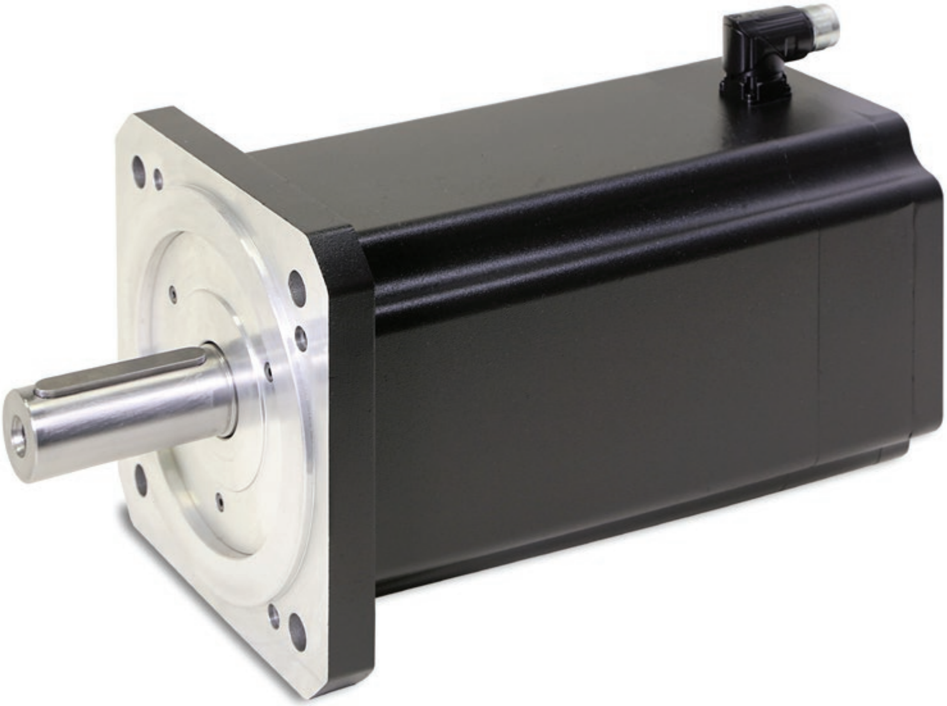
Size

Type

C.6 SMH Motors

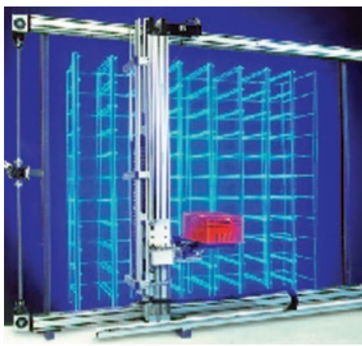


aerospace
climate control
electromechanical
filtration
fluid & gas handling
hydraulics
pneumatics
process control
sealing & shielding



SMH / SMB Series

Low Inertia Servo Motors



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- The user, through its own analysis and testing, is solely responsible for making the final selection of the system and components and assuring that all performance, endurance, maintenance, safety and warning requirements of the application are met. The user must analyze all aspects of the application, follow applicable industry standards, and follow the information concerning the product in the current product catalog and in any other materials provided from Parker or its subsidiaries or authorized distributors.
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Low Inertia Servo Motors - SMH / SMB

Parker Hannifin

The global leader in motion and control technologies

A world class player on a local stage

Global Product Design

Parker Hannifin has more than 40 years experience in the design and manufacturing of drives, controls, motors and mechanical products. With dedicated global product development teams, Parker draws on industry-leading technological leadership and experience from engineering teams in Europe, North America and Asia.

Local Application Expertise

Parker has local engineering resources committed to adapting and applying our current products and technologies to best fit our customers' needs.

Manufacturing to Meet Our Customers' Needs

Parker is committed to meeting the increasing service demands that our customers require to succeed in the global industrial market. Parker's manufacturing teams seek continuous improvement through the implementation of lean manufacturing methods throughout the process. We measure ourselves on meeting our customers' expectations of quality and delivery, not just our own. In order to meet these expectations, Parker operates and continues to invest in our manufacturing facilities in Europe, North America and Asia.

Electromechanical Worldwide Manufacturing Locations

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Littlehampton, United Kingdom
Dijon, France
Offenburg, Germany
Filderstadt, Germany
Milan, Italy

Asia
Wuxi, China
Jangan, Korea
Chennai, India

North America
Rohnert Park, California
Irwin, Pennsylvania
Charlotte, North Carolina
New Ulm, Minnesota

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Milan, Italy

Littlehampton, UK

Filderstadt, Germany

Dijon, France

Low Inertia Servo Motors - SMH / SMB

Overview

Description

The SMH / SMB Series of highly-dynamic brushless servo motors have been design to combine the cutting-edge technology of Parker Hannifin products with an extremely high performance.
Thanks to the innovative "salient pole" technology, the motor's dimensions are considerably reduced with significant advantages in terms of specific torque, overall dimensions and dynamic performance.
Compared to traditional-technology brushless servo motors, the specific torque is approximately 30 % higher, overall dimensions are considerably reduced and, consequently rotor inertias are extremely low.
Thanks to the high quality of Neodymium-Iron-Boron magnets, and also the encapsulation method used to fasten them to the shaft, the SMH/B motors can achieve very high acceleration and withstand high overloads without risk of demagnetisation or detachement of the magnets.
Specific applications for the SMH/B Series include all types especially those for the packaging and handling industry, and all those applications where very high dynamic performances and very low inertias are required.

Features

- High number of feedback options
- Customised windings/voltages
- Increased Inertia option
- Multiple connection options

Application

- Food, Pharma & Beverage
- Packaging Machines
- Material Forming
- Material Handling
- Factory Automation
- Life Science Diagnostic
- Automotive Industry / In-Plant
- Printing Industry
- Textile Machines
- Robotics
- Servo Hydraulic Pumps

Technical Characteristics - Overview

Motor Type	Permanent magnets synchronous servomotor
Rotor Design	Rotor with surface rare earth magnets
Number of poles	8
Power Range	0.1 – 9.4 kW
Torque Range	0.19 – 60 Nm
Speed Range	0 – 7500 min^{-1}
Mounting	Flange with smooth holes
Shaft End	Plain keyed shaft Plain smooth shaft (option)
Cooling	Natural ventilation
Protection Level (IEC60034-5)	IP64 IP65 (option/standard for SM_170)
Feedback sensor	Resolver Absolute Endat or Hiperface Incremental Encoder
Thermal protection	PTC for SMB and KTY compatible with SMH
Other options	Brake Second shaft Increased inertia
Marking	CE UL (SM_40 and SM_170 excluded)
Voltage Supply	80 / 230 / 400 VAC other voltage under request
Temperature Class	Class F
Connections	Rotatable connectors Flying cables Terminal Box (see table option for combination) Special connector (under request)

Technical Characteristics

Technical Data

230 VAC supply voltage

Model	Size	Stall [1]		Nominal [1]			Peak [1]	Inertia		Ke [2] [3]	Kt [2] [3]
		Torque	Current	Torque	Speed	Current	Torque	No brake	With brake		
		T_{065} (T_{105}) [Nm]	I_{065} [A]	T_{n065} [Nm]	n [min^{-1}]	I_{n065} [A]	T_{max} [Nm]	J [$kgmm^2$]	J [$kgmm^2$]	Ke [Vs]	Kt [Nm/A_{rms}]
SM_40 60 0,19	40	0.19	0.78	0.16	6000	0.66	0.6	3.7	-	0.14	0.242
SM_40 60 0,38		0.38	1.2	0.27	6000	0.86	1.17	6.1		0.181	0.31
SM_60 30 0,55	60	0.55 (0.68)	0.7	0.50	3000	0.66	1.7	18	30.5	0.44	0.76
SM_60 45 0,55			1.0	0.39	4500	0.74				0.30	0.53
SM_60 60 0,55			1.4	0.24	6000	0.60				0.23	0.40
SM_60 16 1,4		1.4 (1.7)	0.95	1.35	1600	0.91	4.4	30	42.5	0.85	1.48
SM_60 30 1,4			1.73	1.20	3000	1.50				0.47	0.81
SM_60 45 1,4			2.37	1.00	4500	1.69				0.34	0.59
SM_60 60 1,4			2.98	0.80	6000	1.70				0.27	0.47
SM_60 75 1,4			3.85	0.15	7500	0.41				0.21	0.36
SM_82 10 03	82	3 (3.7)	1.2	2.9	1000	1.2	9	140	183	1.43	2.48
SM_82 16 03			1.8	2.9	1600	1.7				0.96	1.66
SM_82 30 03			3.1	2.7	3000	2.8				0.55	0.96
SM_82 33 03			3.5	2.4	3300	2.8				0.49	0.85
SM_82 45 03			4.7	2.2	4500	3.4				0.37	0.64
SM_82 60 03			6.1	1.5	6000	3.1				0.28	0.49
SM_82 75 03			7.5	0.6	7500	1.6				0.23	0.40
SM_100 16 06	100	6 (9)	3.7	5.8	1600	3.6	18	336	440	0.92	1.60
SM_100 30 06			5.9	5.0	3000	4.9				0.59	1.02
SM_100 45 06			9.4	3.5	4500	5.5				0.37	0.64
SM_100 55 06			11.8	2.6	5500	5.1				0.29	0.51
SM_100 75 06			14.7	0.6	7500	1.5				0.24	0.41
SM_115 16 10	115	10 (12.5)	6.0	9.0	1600	5.4	32	900	1000	0.96	1.66
SM_115 30 10			10.5	8.0	3000	8.4				0.55	0.95
SM_115 40 10			14.7	7.6	4000	11.2				0.39	0.68
SM_115 54 10			18.2	7.1	5400	12.9				0.32	0.55
SM_142 18 15	142	15 (19)	9.7	13.3	1800	8.6	47	1400	1600	0.89	1.54
SM_142 30 15			16.0	12.5	3000	13.4				0.54	0.94
SM_170 11 35	170	35	13.3	30	1100	11.4	111	2900	4500	1.52	2.6
SM_170 16 35			20	28	1600	16.0				1.03	1.8
SM_170 25 35			29	26	2500	22.0				0.69	1.2

(1) Data referred to motor mounted on a steel flange in horizontal position with resolver and without brake. Stall torques refer to motor turning at 100 min^{-1}

(2) Data measured at 20 °C. When "hot" consider -0.09 %/K derating

(3) Manufacturing tolerance ±10 %

400 VAC power supply

Model	Size	Stall [1]		Nominal [1]			Peak [1]	Inertia		Ke [2] [3]	Kt [2] [3]
		Torque	Current	Torque	Speed	Current	Torque	No brake	With brake		
		T_{065} (T_{105}) [Nm]	I_{065} [A]	T_{n065} [Nm]	n [min⁻¹]	I_{n065} [A]	T_{max} [Nm]	J [kgmm²]	J [kgmm²]	Ke [Vs]	Kt [Nm/A_{rms}]
SM_60 30 1,4	60	1.4 (1.7)	0.95	1.2	3000	0.81	4.4	30	42.5	0.81	1.48
SM_60 45 1,4			1.37	1.0	4500	0.98				0.59	1.02
SM_60 60 1,4			1.73	0.8	6000	0.99				0.68	0.81
SM_60 75 1,4			2.15	0.15	7500	0.23				0.38	0.65
SM_82 30 03	82	3 (3.7)	1.8	2.7	3000	1.6	9	140	183	0.96	1.66
SM_82 45 03			2.7	2.2	4500	2.0				0.64	1.11
SM_82 56 03			3.1	1.6	5600	1.7				0.55	0.96
SM_82 60 03			3.5	1.7	6000	2.0				0.49	0.85
SM_82 75 03			4.4	0.6	7500	0.9				0.39	0.68
SM_100 30 06	100	6 (9)	3.7	5.0	3000	3.1	18	336	440	0.92	1.60
SM_100 45 06			5.6	3.5	4500	3.3				0.62	1.07
SM_100 56 06			5.9	2.5	5600	2.4				0.59	1.02
SM_100 75 06			9.4	0.6	7500	0.9				0.37	0.64
SM_115 20 10	115	10 (12.5)	4.5	9.0	2000	4.06	32	900	1000	1.28	2.22
SM_115 30 10			6.0	8.0	3000	4.82				0.96	1.66
SM_115 40 10			8.0	7.6	4000	6.05				0.73	1.26
SM_115 56 10			10.5	6.0	5600	6.30				0.55	0.95
SM_142 20 15	142	15 (19)	6.4	13.0	2000	5.5	47	1400	1600	1.36	2.35
SM_142 30 15			9.7	12.5	3000	8.1				0.89	1.54
SM_142 45 15			14.4	10.9	4500	10.5				0.60	1.04
SM_142 56 15			16.0	9.2	5600	9.8				0.54	0.94
SM_142 10 17		17 (21)	3.5	16.4	1000	3.4	54			2.83	4.90
SM_142 30 17			9.6	14.0	3000	8.1				1.02	1.77
SM_142 56 17			15.8	10.6	5600	9.8				0.62	1.08
SM_170 10 35	170	35	6.8	31	1000	6.1	111	2900	4500	2.95	5.1
SM_170 20 35			13.3	27	2000	10.3				1.52	2.6
SM_170 27 35			18	22	2700	11				1.15	2.0
SM_170 30 35			20	19	3000					1.03	1.8
SM_170 10 60		60	11.7	53	1000	10.4	190	5800	7400	2.95	5.1
SM_170 20 60			22.6	44	2000	16.6				1.53	2.7
SM_170 30 60			35.7	30	3000	17.9				0.97	1.7

(1) Data referred to motor mounted on a steel flange in horizontal position with resolver and without brake. Stall torques refer to motor turning at 100 min⁻¹
(2) Data measured at 20 °C. When "hot" consider -0.09 %/K derating
(3) Manufacturing tolerance data ±10 %

STANDARDS

In compliance with: 2006/95 EC

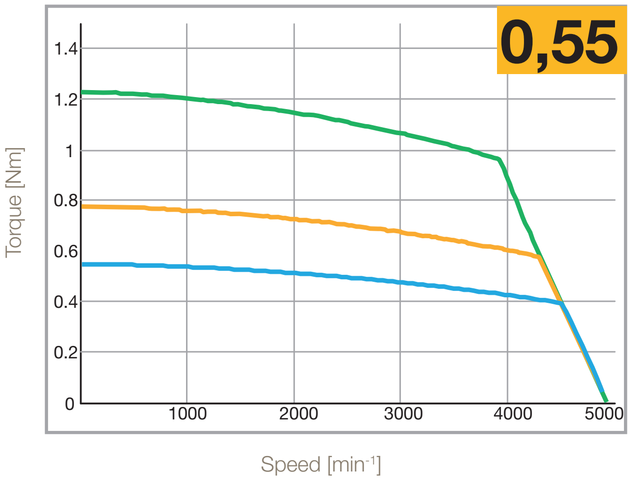
- EN60034-1
- EN60034-5
- EN60034-5/A1

Marked CE **Marked** cULus (except SM_40 and SM_170)

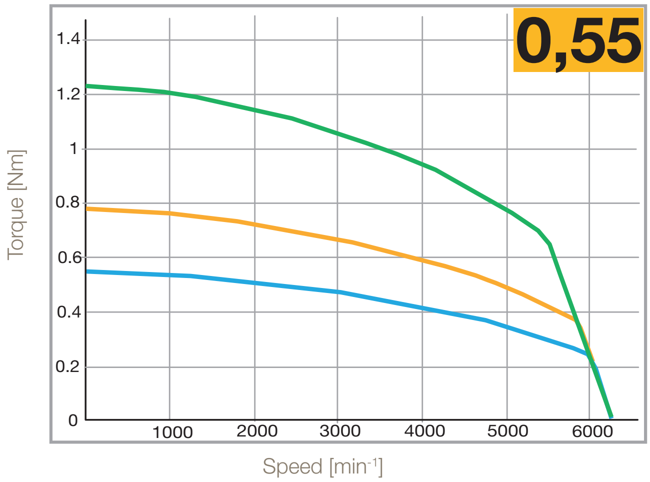
Speed Torque Curves

SMH/B60

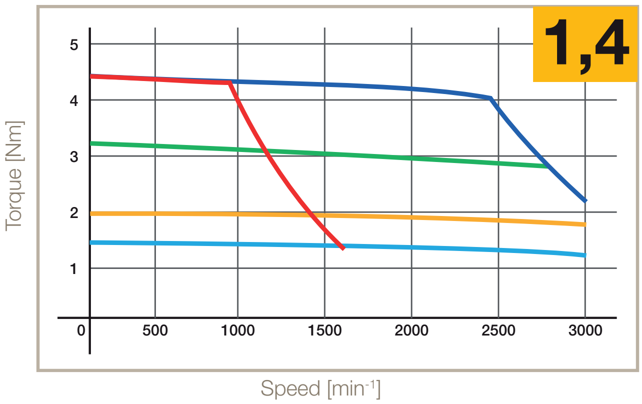
4500 min^{-1} 230 V



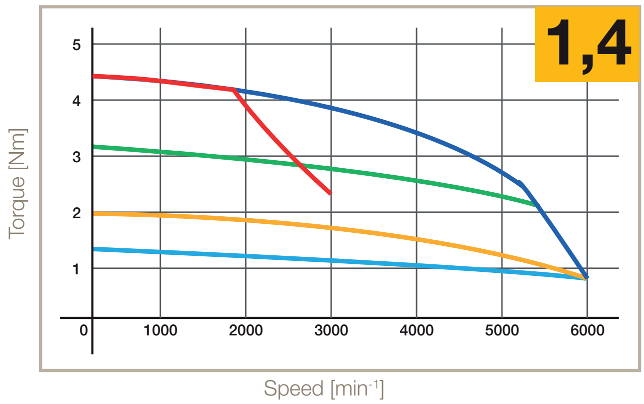
6000 min^{-1} 230 V



1600 min^{-1} 230 V - 3000 min^{-1} 400 V



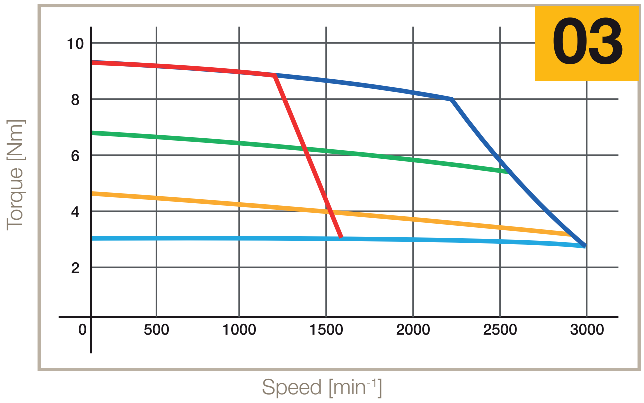
3000 min^{-1} 230 V - 6000 min^{-1} 400 V



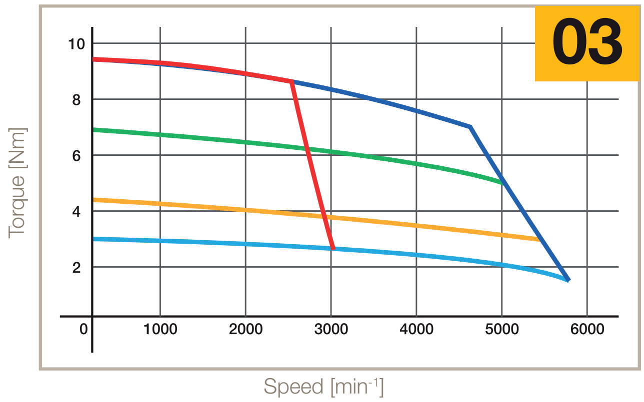
- S1 65 K, ΔT
- S3 10 %, 5 min, 400 V
- S3 50 %, 5 min
- S3 10 %, 5 min, 230 V
- S3 50 %, 5 min
- S3 20 %, 5 min

SMH/B82

1600 min^{-1} 230 V - 3000 min^{-1} 400 V

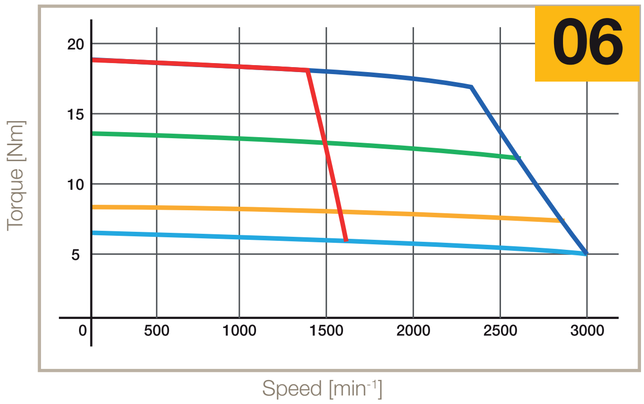


3000 min^{-1} 230 V - 5600 min^{-1} 400 V

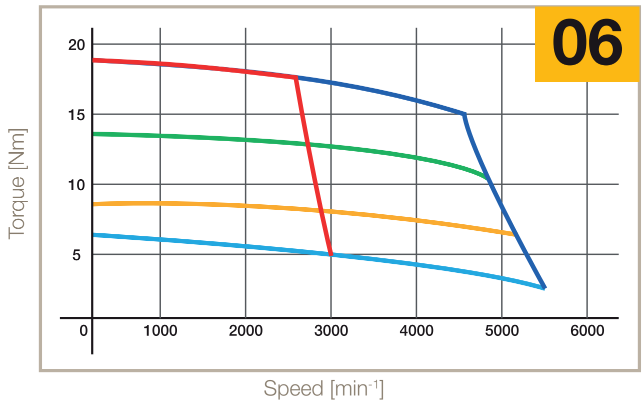


SMH/B100

1600 min^{-1} 230 V - 3000 min^{-1} 400 V

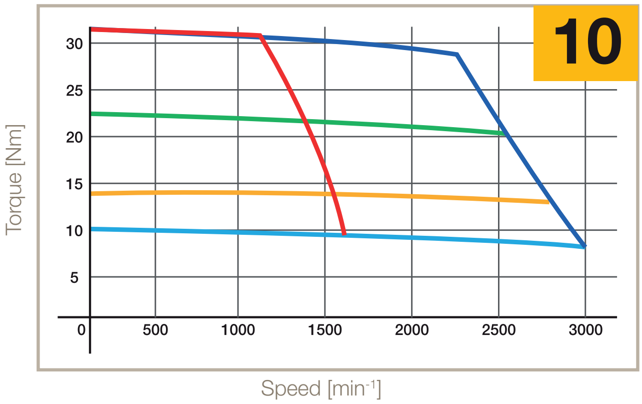


3000 min^{-1} 230 V - 5600 min^{-1} 400 V

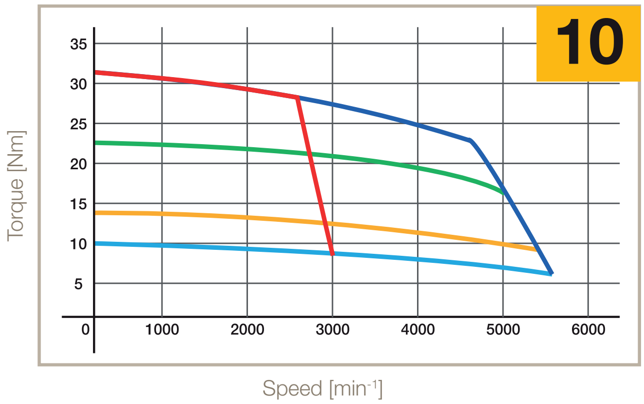


SMH/B115

1600 min^{-1} 230 V - 3000 min^{-1} 400 V



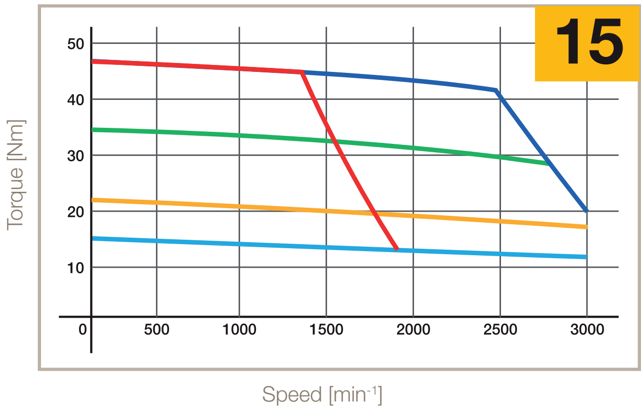
3000 min^{-1} 230 V - 5600 min^{-1} 400 V



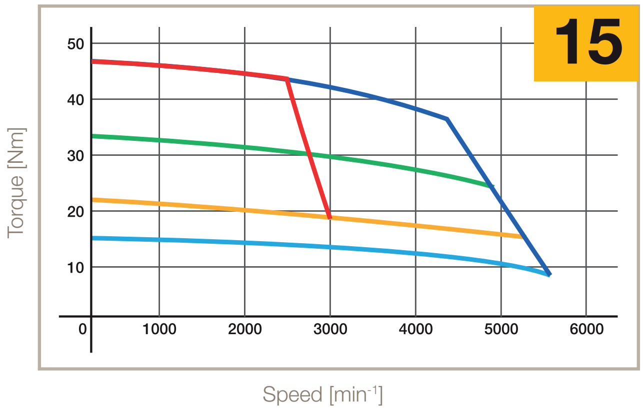
- S1 65 K, ΔT
- S3 10 %, 5 min, 400 V
- S3 50 %, 5 min
- S3 10 %, 5 min, 230 V
- S3 50 %, 5 min
- S3 20 %, 5 min

SMH/B142

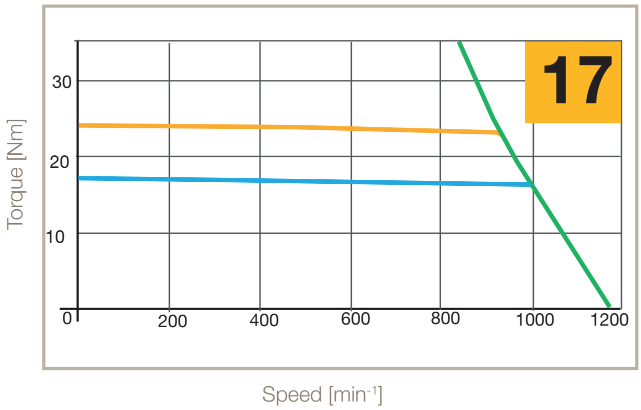
1800 min⁻¹ 230 V - 3000 min⁻¹ 400 V



3000 min⁻¹ 230 V - 5600 min⁻¹ 400 V

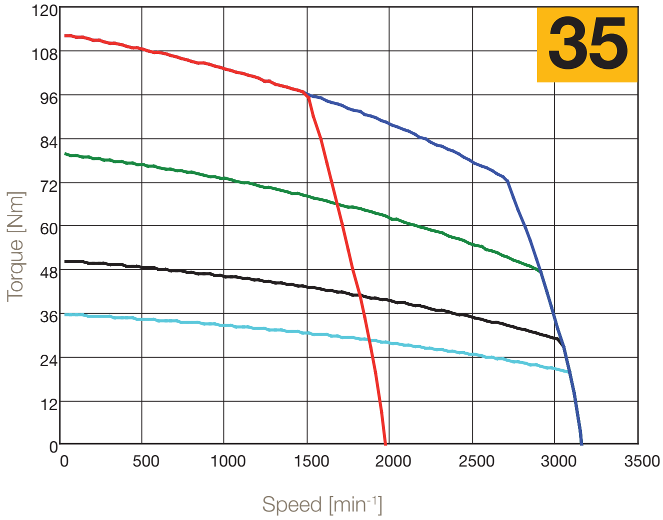


1000 min⁻¹ 400 V

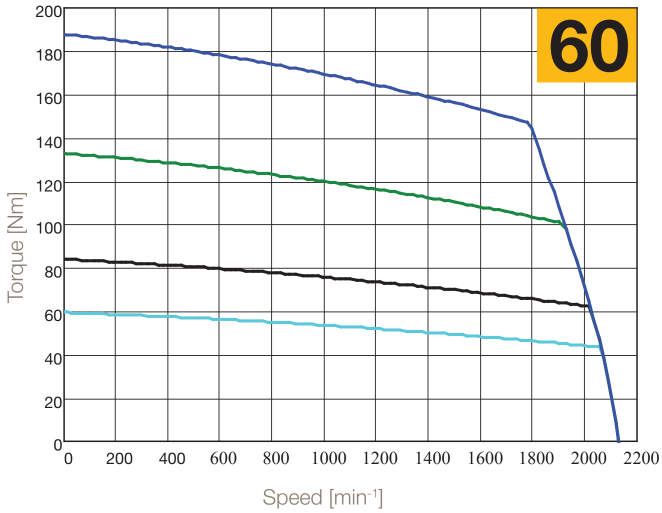


SMH/B170

1600 min⁻¹ 230 V - 3000 min⁻¹ 400 V

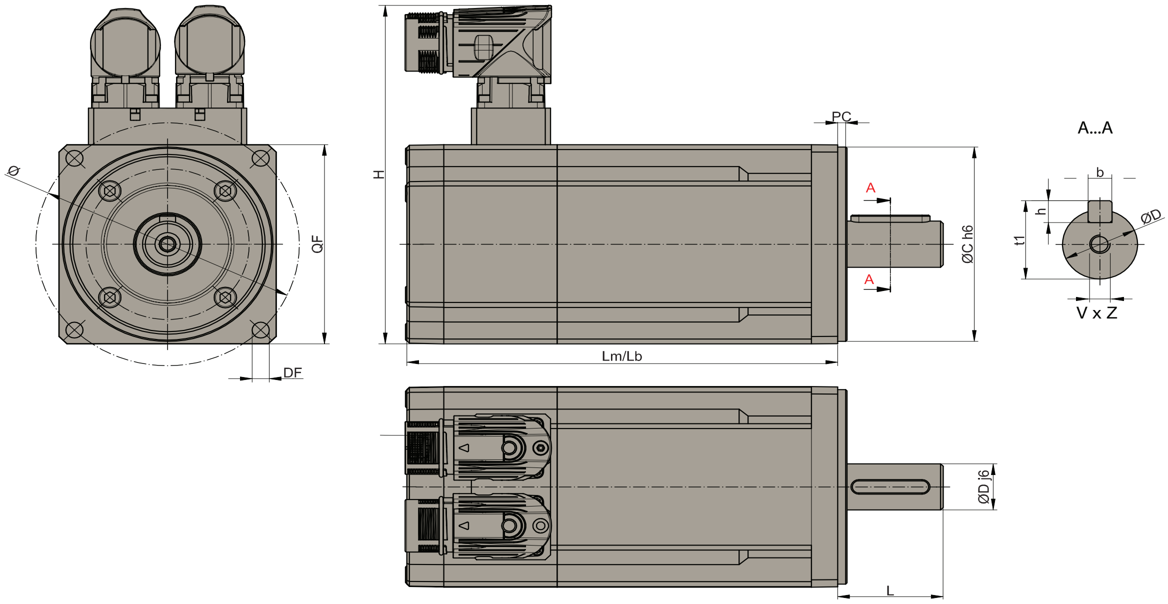


2000 min⁻¹ 400 V



- S1 65 K, ΔT
- S3 10 %, 5 min, 400 V
- S3 50 %, 5 min
- S3 10 %, 5 min, 230 V
- S3 50 %, 5 min
- S3 20 %, 5 min

Dimensions of Standard Motors with Resolver Feedback



Dimensions [mm]

Motors Size			LM LB	Weight [kg]	DxL	bxh	t1	VxZ	H	C	Ø	DF	PC	QF	Order Code QF
SMH /B	40	0,19	87.5 119.5	0.53 n.a.	8x20	3x3	9.2	n.a.	60 Layout 2Y	30	50	4.3	2.5	40	5
	40	0,38	105.5 137.5	0.68 n.a.	8x20	3x3	9.2	n.a.	60 Layout 2Y	30	50	4.3	2.5	40	5
	60	0,55	91.2 137	1 1.3	9x20 11x23	3x3 4x4	10.2 12.5	- M4x10	118 Layout 2I	40	63	5.5	2.5	60	8
										60	75	6	2.5	70	5
	60	1,4	129.5 161	1.5 1.8	9x20 11x23	3x3 4x4	10.2 12.5	- M4x10		40	63	5.5	2.5	60	8
										60	75	6	2.5	70	5
	82	03	159 202	3.6 4.3	11x23[2] 14x30	4x4 5x5	12.5 16	M4x10 M5x12.5	140 Layout 2I	60	75	6	2.5	70	7
	82	03	163.5 206.5	3.6 4.3	11x23[2] 14x30 19x40[1]	4x4 5x5 6x6	12.5 16 21.5	M4x10 M5x12.5 M6x16		80	100	6.5	3.5	82	8
										95	115	9	3.5	100	5
	100	06	191.5 238.5	4.7 5.3	19x40 24x50	6x6 8x7	21.5 27	M6x16 M8x19	157.5 Layout 2I	80	100	7	3.5	100	8
										95	115	9	3.5	100	5
	115	10	220 265	7.7 9.7	19x40 24x50 28x60	6x6 8x7 8x7	21.5 27 31	M6x16 M8x19 M10x22	157.5 Layout 2I	95	115	9	3.5	115	9
										95	130	9	3.5	115	8
										110	130	9	3.5	130	7
										130	165	11	3.5	145	5
	142	15	243 293	13 16	19x40 24x50 28x60	6x6 8x7 8x7	21.5 27 31	M6x16 M8x19 M10x22	185 Layout 2I	130	165	11	3.5	142	5
	170	35	306	30	38x80	10x8	41	M12x32	212.3 Layout 2I	180	215	14	4	205	5
	170	60	409	50	38x80	10x8	41	M12x32	212.3 Layout 2I	180	215	14	4	205	5

LM: Motor’s length without brake and with resolver
LB: Motor’s length with brake and resolver
DxL: Shaft diameter x shaft lenght
bxh: Key dimension
t1: Overall shaft height
VxZ: Shaft hole depth
C: Centering

H: Height
DF: Fixing holes
Ø: Interaxis hole
QF: Mounting flange
PC: Centre Depth

[1] not available with flange 7
(2) only for torque <2 Nm

Options

Parker SMH / SMB family motors are available with standard and custom options to adapt motor on your application.
If the option for your application is not listed, please consult our technical department.

Holding Brake

All SMH / SMB motors are available with option holding brake.
The fail-safe (supply voltage 24 VDC ±10 %) holding brake is incorporated in the motor at the opposite side of the front flange (SM_170 front side) and is applied when there is no voltage present. Because of the power loss caused by the brake, torque values must be reduced by 5 %. The holding brakes shall be used with the motor at a standstill and not for dynamic braking. For maintenance, please refer to technical manual

Motor	Voltage [V]	Current [A]	Torque @20 °C [Nm]	Added Length with resolver [mm]	Added Weight [kg]	Added Inertia [kgmm²]
SMH / SMB40	24	0.25	0.4	32	0.15	-
SMH / SMB60		0.34	2.2	31.5	0.3	12.5
SMH / SMB82		0.5	4.5	43	0.7	43
SMH / SMB100		0.67	9	47	0.6	104
SMH / SMB115		0.67	9	45	2	100
SMH / SMB142		0.75	22	50	3	200
SMH / SMB170		1.67	72	-	2.9	1600

Medium Inertia

Where the application needs different values of inertia, SMH / SMB can provide a standard adder.

Motor	Added inertia [kgmm²]	Added length with resolver [mm]	Added weight [kg]
SMH / SMB60	29	31.5	0.32
SMH / SMB82	270	43	0.91
SMH / SMB100	284	47	0.68
SMH / SMB115	900	45	2.28
SMH / SMB142	690	50	2.49
SMH / SMB170	consult Parker	consult Parker	consult Parker

Feedback

Motors may be eqquiped with various feedback types in order to meet the different requirements for precision, signal that the application needs. The standard motor includes the resolver feedback. Hiperface Encoder, DSL Encoder, EnDat Encoder, Incremental Encoder are available like the following tables.

Resolver

Poles	2
Transformation ratio	0.5
Operating temperature	-50...+150 °C
SM_ associations	All Sizes

Incremental Encoder with Hall Sensor

Code	A1	A2	A3	B3	C4	D3
Resolution [C/T]	2000	2048	4096	2048	5000	5000
Poles	8					
System accuracy	±32"	±32"	±16"	±32"	±13"	±13"
Voltage	+5 VDC ±5 % - 200 mA					
Reference mark	Yes					
Max speed [min^{-1}]	6000					
Output circuit	Line drive differential mode 20 mA					
Operating temperature	-20 °C...+100 °C		-20 °C...+85 °C	-20 °C...+100 °C		-20 °C...+85 °C
SM_ motors associations						
SM_40	N	N	N	N	N	N
SM_60	N	N	N	Y (+17 mm length)	N	Y (+17 mm length)
SM_82	Y	Y	Y	N	Y	N
SM_100	Y	Y	Y	N	Y	N
SM_115	Y	Y	Y	N	Y	N
SM_142	Y	Y	Y	N	Y	N
SM_170	Y	Y	Y	N	Y	N

Hiperface Absolute Encoder

Code	S1	S2	S3	S4	S5	S6
Type	Optical					
Turn	Single	Multi	Single	Multi	Single	Multi
Incremental signals	1 V_{PP}				-	-
Line count	1024		128		-	-
Resolution	32 768 (15 bit)		4096 (12 bit)		262 144 (18 bits)	
Absolute rotation	1	4096	1	4096	1	4096
System accuracy	±45"		±320"		±40"	
Power supply	8 VDC				7...12 VDC	
Max speed [min^{-1}]	6000		12 000	9000		
Temperature	-20 °C...+115 °C		-20 °C...+110 °C		20 °C...+105 °C	
Safety integrity level	SIL2 (IEC 61508), SILCL2 (IEC 62061)				SIL2 (IEC 61508), SILCL2 (IEC 62061)	
SM_ motors associations						
SM_40	N	N	N	N	N	N
SM_60	N		Y (+17 mm length without brake) (+30 mm length with brake)		Y (+17 mm length without brake) (+30 mm length with brake)	
SM_82	Y (+17 mm length without brake) (+30 mm length with brake)		Y	Y	Y	Y
SM_100	Y (+20 mm length)				Y (+20 mm length)	
SM_115	Y	Y	Y	Y	Y	Y
SM_142	Y	Y	Y	Y	Y	Y
SM_170	Y	Y	Y	Y	Y	Y

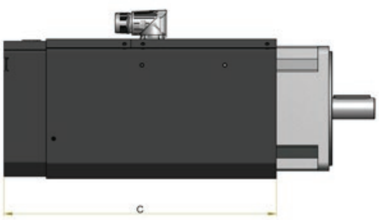
Code	A6	A7	C6	C7
Type	Optical			
Turn	Single	Multi	Single	Multi
Incremental signals	1 V_{PP}			
Line count	1024		128	
Resolution	32 768 (15 bit)		4096 (12 bit)	
Absolute rotation	1	4096	1	4096
System accuracy	±45"		±320"	
Power supply	8 VDC			
Max speed [min^{-1}]	6000		12 000	9000
Temperature	-20 °C...+115 °C		-20 °C...+110 °C	
Safety integrity level	Not Available		Not Available	
SM_ motors associations				
SM_40	N	N	N	N
SM_60	N		Y (+17 mm length without brake) (+30 mm length with brake)	
SM_82	Y (+17 mm length without brake) (+30 mm length with brake)		Y	Y
SM_100	Y (+20 mm length)			
SM_115	Y	Y	Y	Y
SM_142	Y	Y	Y	Y
SM_170	Y	Y	Y	Y

EnDat Absolute Encoder

Code	B9	D5	F2	F4
Type	Inductive	Optical		Inductive
Turn	Multi			
Incremental signals	1 V_{PP}			
Line count	32	512		16
Positions per revolutions	131 072 (17 bit)	8192 (13 bit)		262 144 (18 bit)
Distinguishable revolutions	4096	4096		
System accuracy	±400"	±60"		±480"
Power supply	5 VDC			
Max speed [min⁻¹]	12 000	7000	12 000	
Temperature	-20 °C...+115 °C	-30 °C...+115 °C	-40 °C...+115 °C	-20 °C...+115°C
Absolute position values	EnDat 2.1	EnDat 2.2		EnDat 2.1
Safety integrity level	Not Available			
SM_ motors associations				
SM_40	N	N	N	N
SM_60	N	N	Y (+17 mm length without brake) (+9 mm length with brake)	
SM_82	Y (+22.5 mm length without brake) (+18 mm length with brake)		N	N
SM_100	Y (+20 mm length)		N	N
SM_115	Y	Y	N	N
SM_142	Y	Y	N	N
SM_170	Y	Y	N	N

Servofan kit

Designed for the SMH/SMB servo motors family, the new Servofan kit allows extra performances over and above the specified motor torque rating.
Brushless servo motors are meant for high dynamic applications and where the functionality is un-constant (S3 Cycle). In this conditions the new Servofan kit increases by 25% the motor torque and it also permits the use in continuos duty (S1) improving the performances.
Suitable for 100-115, 142 and 170mm frames sizes within the SMB/SMH ranges, the kit is available with an IP20 rating and is ideal for deployment in applications within food/ packaging, hydraulic servo pump application, material forming, factory automation and material handling sectors. For customers who already have motors in the specified frame sizes and would like more torque the new Servofan kit can be purchased separately and added.



Dimensions

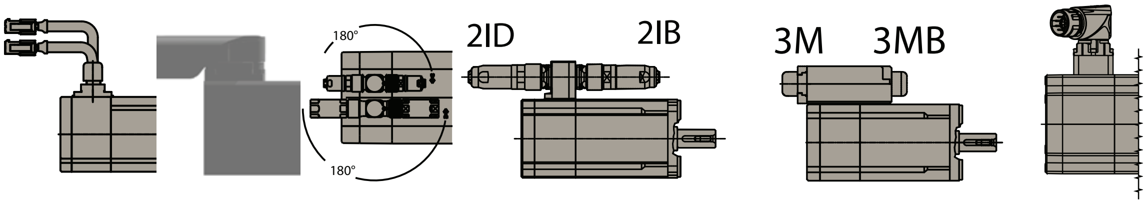
Model	A	B	C
SF-1000-00	131,7	128	271
SF-1420-00	162	159	296
SF-1701-00	184	186	365
SF-1702-00			465

Order code

	1		2	3		4
Order example	SF	-	100	00	-	00

1	**Servofan kit**	
	SF	Servofan kit
2	**SMH-SMB motor size**	
	100	For SMH-SMB size 100 or 115
	142	For SMH-SMB size 142
	170	For SMH-SMB size 170
3	**Motor lenght**	
	0	Standard for all size except size 170
	1	Only for 170 size - Lenght 1 - 35Nm
	2	Only for 170 size - Lenght 2 - 60Nm
4	**Special execution**	
	00	Standard version
	01	Special version without connectors

Layout and Connectors



	200 mm Flying leads with molex plugs 0V	Y-Tech rotatable connector 2Y	2x Parallel upright connectors 2I	2x Forward facing connectors 2IB	2x Rear facing connectors 2ID	Terminal box rear facing 3M	Terminal box forward facing 3MB	Hiperface DSL® Connector (IZ)
SMH__40	N	Y	N	N	N	N	N	N
SMH__60	Y	Y	Y	Y	N	N	N	Y
SMH__82	N	N	Y	Y	N	N	N	Y
SMH__100	N	N	Y	Y	N	N	N	Y
SMH__115	N	N	Y	Y	N	N	N	Y
SMH__142	N	N	Y	Y	N	N	N	Y
SMH__170	N	N	Y	N	N	N	N	Y
SMB__40	N	Y	N	N	N	N	N	N
SMB__60	Y	Y	Y	Y	Y	Y	Y	N
SMB__82	N	N	Y	Y	Y	Y	Y	N
SMB__100	N	N	Y	Y	Y	Y	Y	N
SMB__115	N	N	Y	Y	Y	Y	Y	N
SMB__142	N	N	Y	Y	Y	Y	Y	N
SMB__170	N	N	Y	N	N	N	N	N
SME__60	N	Y	N	Y	Y	N	N	Y
SME__82	N	N	N	Y	Y	N	N	Y
SME__100	N	N	N	Y	Y	N	N	Y
SME__115	N	N	Y	N	N	N	N	Y
SME__142	N	N	Y	N	N	N	N	Y
SME__170	N	N	Y	N	N	N	N	Y

Power connector (0V)

6	5	4
3	2	1

Pin	Description
1	GND - shield
2	Brake 0 VDC
3	Brake +24 VDC
4	W
5	V
6	U

Part number	
CONMOT6M	Female Connector

Resolver connector (0V)

12	11	10	9	8	7
6	5	4	3	2	1

Pin	Description
1	n.c.
2	n.c.
3	n.c.
4	PTC
5	PTC
6	GND - shield
7	SIN +
8	SIN -
9	COS +
10	COS -
11	EXTC -
12	EXTC +

Part number	
CONRES12M	Female Connector

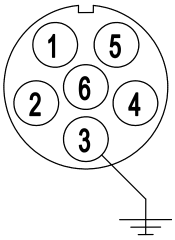
Hiperface connector (0V)

12	11	10	9	8	7
6	5	4	3	2	1

Pin	Description
1	SIN +
2	SIN -
3	RS485 +
4	0 V
5	PTC
6	PTC
7	VDC +
8	COS +
9	COS -
10	RS485 -
11	GND - shield
12	n.c.

Part number	
CONRES12M	Female Connector

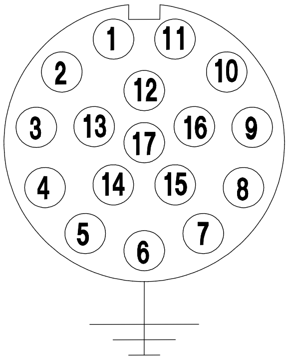
Power connector (2I, 2IB, 2ID)



Pin	Description
1	U
2	V
3	GND - shield
4	Brake +24 VDC
5	Brake 0 VDC
6	W

Part number	
CONMOT82F	Female Connector

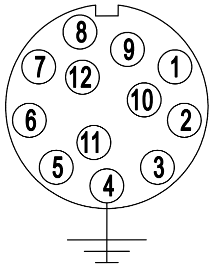
Incremental encoder connector (2I, 2IB, 2ID)



Pin	Description	
1	5 V	
2	0 V	
3	A +	
4	A -	
5	B +	
6	B -	
7	Z +	
8	PTC	KTY -
6	PTC	KTY +
10	Z -	
11	Hall A +	
12	Hall A -	
13	Hall B +	
14	Hall B -	
15	Hall C +	
16	Hall C -	
17	n.c.	

Part number	
CONENCF	Female Connector

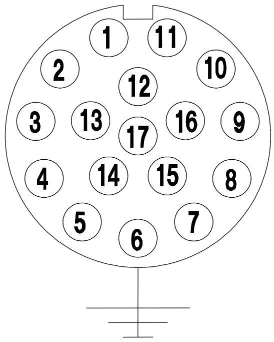
Resolver connector (2I, 2IB, 2ID)



Pin	Description	
1	SIN -	
2	SIN +	
3	n.c.	
4	GND - shield	
5	n.c.	
6	n.c.	
7	EXCT -	
8	PTC	KTY -
9	PTC	KTY +
10	EXCT +	
11	COS +	
12	COS -	

Part number	
CONRES82F	Female Connector

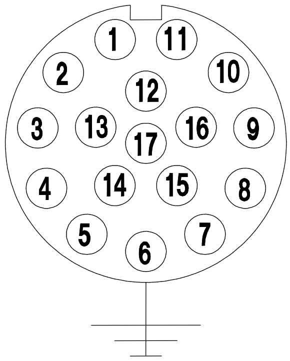
Absolute encoder SINCOS - EnDat (2I, 2IB, 2ID)



Pin	Description	
1	UP Sensor	
2	n.c.	
3	n.c.	
4	0 V Sensor	
5	PTC	KTY -
6	PTC	KTY +
7	UP	
8	CK +	
9	CK -	
10	0 V	
11	GND - shield	
12	B +	
13	B -	
14	Data +	
15	A +	
16	A -	
17	Data -	

Part number	
CONENCF	Female Connector

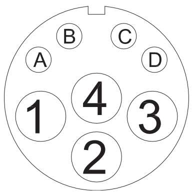
Absolute encoder SINCOS - Hiperface (2I, 2IB, 2ID)



Pin	Description	
1	SIN +	
2	SIN -	
3	RS485 +	
4	n.c.	
5	n.c.	
6	n.c.	
7	GND - shield	
8	PTC	KTY -
9	PTC	KTY +
10	+ VDC	
11	COS +	
12	COS -	
13	RS485 -	
14	n.c.	
15	n.c.	
16	n.c.	
17	n.c.	

Part number	
CONRES82F	Female Connector

Hiperface DSL® Connector (IZ)



Pin	Description
1	U
2	GND
3	V
4	W
A	Brake +
B	Brake -
C	Signal +
D	Signal -

Part number	
CONMOT2IZF	Female Connector

Associated Drives

Motor	Rated Speed [min⁻¹]	Stall Current [A]	PSD1S	PSD1M
	230 VAC supply voltage			
SM_40 60 0,19	6000	0.78	PSD1S_1200	PSD1M_1222
SM_40 60 0,38	6000	1.2	PSD1S_1200	PSD1M_1222
SM_60 30 0,55	3000	0.7	PSD1S_1200	PSD1M_1222
SM_60 45 0,55	4500	1	PSD1S_1200	PSD1M_1222
SM_60 60 0,55	6000	1.4	PSD1S_1200	PSD1M_1222
SM_60 16 1,4	1600	0.95	PSD1S_1200	PSD1M_1222
SM_60 30 1,4	3000	1.73	PSD1S_1200	PSD1M_1222
SM_60 45 1,4	4500	2.37	PSD1S_1300	PSD1M_1433
SM_60 60 1,4	6000	2.98	PSD1S_1300	PSD1M_1433
SM_60 75 1,4	7500	3.85	PSD1S_1300	PSD1M_1433
SM_82 10 03	1000	1.2	PSD1S_1200	PSD1M_1222
SM_82 16 03	1600	1.8	PSD1S_1200	PSD1M_1222
SM_82 30 03	3000	3.1	PSD1S_1300	PSD1M_1433
SM_82 33 03	3300	3.5	PSD1S_1300	PSD1M_1433
SM_82 45 03	4500	4.7	PSD1S_1300	PSD1M_1433
SM_82 60 03	6000	6.1	n.a.	PSD1M_1433
SM_82 75 03	7500	7.5	n.a.	PSD1M_1433
SM_100 16 06	1600	3.7	PSD1S_1300	PSD1M_1433
SM_100 30 06	3000	5.9	n.a.	PSD1M_1433
SM_100 45 06	4500	9.4	n.a.	PSD1M_1630
SM_100 55 06	5500	11.8	n.a.	PSD1M_1630
SM_100 75 06	7500	14.7	n.a.	PSD1M_1630
SM_115 16 10	1600	6	n.a.	PSD1M_1433
SM_115 30 10	3000	10.5	n.a.	PSD1M_1630
SM_115 40 10	4000	14.7	n.a.	PSD1M_1630
SM_115 54 10	5400	18.2	n.a.	PSD1M_1800
SM_142 18 15	1800	9.7	n.a.	PSD1M_1630
SM_142 30 15	3000	16	n.a.	PSD1M_1800
SM_170 11 35	1100	13.3	n.a.	PSD1M_1630
SM_170 16 35	1600	20	n.a.	PSD1M_1800
SM_170 25 35	2500	29	n.a.	PSD1M_1800
	400 VAC supply voltage			
SM_60 30 1,4	3000	0.95	n.a.	PSD1M_1222
SM_60 45 1,4	4500	1.37	n.a.	PSD1M_1222
SM_60 60 1,4	6000	1.73	n.a.	PSD1M_1222
SM_60 75 1,4	7500	2.15	n.a.	PSD1M_1433
SM_82 30 03	3000	1.8	n.a.	PSD1M_1222
SM_82 45 03	4500	2.7	n.a.	PSD1M_1433
SM_82 56 03	5600	3.1	n.a.	PSD1M_1433
SM_82 60 03	6000	3.5	n.a.	PSD1M_1433
SM_82 75 03	7500	4.4	n.a.	PSD1M_1433
SM_100 30 06	3000	3.7	n.a.	PSD1M_1433
SM_100 45 06	4500	5.6	n.a.	PSD1M_1433
SM_100 56 06	5600	5.9	n.a.	PSD1M_1433
SM_100 75 06	7500	9.4	n.a.	PSD1M_1630
SM_115 20 10	2000	4.5	n.a.	PSD1M_1433
SM_115 30 10	3000	6.0	n.a.	PSD1M_1433
SM_115 40 10	4000	8.0	n.a.	PSD1M_1433
SM_115 56 10	5600	10.5	n.a.	PSD1M_1630
SM_142 20 15	2000	6.4	n.a.	PSD1M_1433
SM_142 30 15	3000	9.7	n.a.	PSD1M_1630
SM_142 45 15	4500	14.4	n.a.	PSD1M_1630
SM_142 56 15	5600	16	n.a.	PSD1M_1800
SM_170 10 35	1000	6.8	n.a.	PSD1M_1630
SM_170 20 35	2000	13.3	n.a.	PSD1M_1630
SM_170 27 35	2700	18	n.a.	PSD1M_1800
SM_170 30 35	3000	20	n.a.	PSD1M_1800
SM_170 10 60	1000	11.7	n.a.	PSD1M_1630
SM_170 20 60	2000	22.6	n.a.	PSD1M_1800
SM_170 30 60	3000	35.7	n.a.	n.a.

Order Code

Serie SMH / SMB / SME

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Order example	**SMH**	**A**	**60**	**30**	**1,4**	**5**	**9**		**2I**		**64**	**A6**	**M**	**2**

1	**Type Of Motor (mandatory field)**
SMH	Motor with Resolver for PSD/C3
SMB	Motor with Resolver for TPDM/SLVDN
SME	Motor with Encoder for TPDM/SLVDN

2	**Brake Option**
empty field	No Brake Option
A	Motor with Holding Brake

3	**Motor Frame Size (mandatory field)**
40	Torque range 0.19 Nm or 0.35 Nm
60	Torque range 0.55 or 1.4 Nm
82	Torque range 3 Nm
100	Torque range 6 Nm
115	Torque range 10 Nm
142	Torque range 15 or 17 Nm
170	Torque range 35 or 60 Nm

4	**Winding (mandatory field)**
nn	min^{-1} (x100) see "Technical Data" (page 6)

5	**Motor Torque (mandatory field)**
nn	Torque [Nm] see "Technical Data" (page 6)

6	**Flange (mandatory field)**
5	All sizes
7	Only for Size 82 and 115
8	Only for Size 60, 82, 100 and 115
9	Only for Size 115

7	**Shaft (mandatory field)**
8	8x20 mm for size 40
9	9x20 mm for size 60
11	11x23 mm for size 60
14	14x30 mm for size 82
19	19x40 mm for size 82/100/115/142
24	24x50 mm for size 100/115/142
28	28x60 mm for size 115/142
38	38x80 mm for size 170

8	**Key Shaft option**
Empty field	Shaft with Key
S	Shaft without key

9	**Layout - Connectors (mandatory field)**
0V	Cable exit and Molex Flying connectors - 200 mm above
2I	Rotatable Interconnectron receptacles
2IB	90° Interconnectron receptacles - forward facing
2ID	90° Interconnectron receptacles - rear facing
3M	Terminal box rear facing
3MB	Terminal box forward facing
2Y	Y-Tech connectors
IZ	DSL® connectore (not for size 40)

10	**Female connectors option (only for SMB/SME)**
Empty field	With Female / flying connectors
W	Without Female / flying connectors

11	**Protection Degree (mandatory field)**
64	IP64
65	IP65 (standard for SMB170)

12	**Feedback**
Empty field	Standard Resolver
A1	Encoder 2000 ppr + Hall - TAMAGAWA OIH48
A2	Encoder 2048 ppr + Hall - TAMAGAWA OIH48
A3	Encoder 4096 ppr + Hall - TAMAGAWA OIH48
A6	SinCos Hiperface Encoder Single-Turn - STEGMANN SRS50/52
A7	SinCos Hiperface Encoder Multi-Turn - STEGMANN SRS50/52
B3	Encoder 2048 ppr + Hall - TAMAGAWA OIH35
B9	SinCos EnDat Encoder Multi-Turn - HEIDENHAIN EQI1331
C4	Encoder 5000 ppr + Hall - TAMAGAWA OIH48
C6	SinCos Hiperface Encoder Single-Turn - STEGMANN SKS36
C7	SinCos Hiperface Encoder Multi-Turn - STEGMANN SKM36
D3	Encoder 5000ppr + Hall - TAMAGAWA OIH35
D5	SinCos EnDat Encoder Multi-Turn - HEIDENHAIN EQN1325
F2	SinCos EnDat Encoder Multi-Turn - HEIDENHAIN EQN1125
F4	SinCos EnDat Encoder Multi-Turn - HEIDENHAIN EQI1130
S1	SinCos Hiperface Encoder Single-Turn - STEGMANN SRS50S, SIL2
S2	SinCos Hiperface Encoder Multi-Turn - STEGMANN SRS50S, SIL2
S3	SinCos Hiperface Encoder Single-Turn - STEGMANN SKS36S, SIL2
S4	SinCos Hiperface Encoder Multi-Turn - STEGMANN SKM36S, SIL2
S5	Hiperface DSL® Encoder Feedback SIL2 32768 steps/rev Single Turn
S6	Hiperface DSL® Encoder Feedback SIL2 32768 steps/rev x 4096 Multi Turn

13	**Option Inertia**	
	Empty field	Standard Inertia
	M	Medium Inertia
14	**Voltage**	
	0	80 V
	2	220-230 V (Standard)
	4	380-400 V (Standard)

Order Code

Motor Power Cable for SMH / SMB Motors

	1	2	3	4		5		6		7		8
Order example	**CBM**	**005**	**H**	**D**	**-**	**M15**	**-**	**PSX**	**-**	**0010**	**-**	**00**

1	**Power Cable Drive**	
	CBM	Power cable drive
2	**Section [mm²]**	
	005	0.5 mm²
	007	0.7 mm²
	010	1 mm²
	015	1.5 mm²
	025	2.5 mm²
3	**Cable**	
	S	Standard
	H	High Flex
4	**Brake**	
	0	Power cable standard - without brake
	B	Power cable standard - with brake
	D	DSL® Power cable with brake
5	**Motor Connector**	
	M15	M15 Interconnectron connector
	M23	M23 Interconnectron connector
	M40	M40 Interconnectron connector
6	**Drive**	
	PSX	Parker PSD1-S
	PMX	Parker PSD1-M
	SDX	Parker Servonet DC
7	**Length**	
	0000	Cable length 4 digits (example 50 m = 0500)*
8	**Special Execution**	
	00	Standard

* Available length in meter: 1; 2.5; 5; 7.5; 10; 15; 20; 25; 30; 35; 40; 45; 50

Motor Feedback Cable for SMH / SMB Motors

	1	2	3	4		5		6		7		8
Order example	**CBF**	**RE0**	**H**	**0**	**-**	**M15**	**-**	**PSX**	**-**	**0010**	**-**	**00**

1	**Power Cable Drive**	
	CBF	Feedback cable drive
2	**Feedback**	
	RE0	Resolver
3	**Cable**	
	H	High Flex
4	**Brake**	
	0	Power cable standard - without brake
5	**Motor Connector**	
	M15	M15 Interconnectron connector
	M23	M23 Interconnectron connector
	M40	M40 Interconnectron connector
6	**Drive**	
	PSX	Parker PSD1-S
	PMX	Parker PSD1-M
	SDX	Parker Servonet DC
7	**Length**	
	0000	Cable length 4 digits (example 50 m = 0500)*
8	**Special Execution**	
	00	Standard

* Available length in meter: 1; 2.5; 5; 7.5; 10; 15; 20; 25; 30; 35; 40; 45; 50

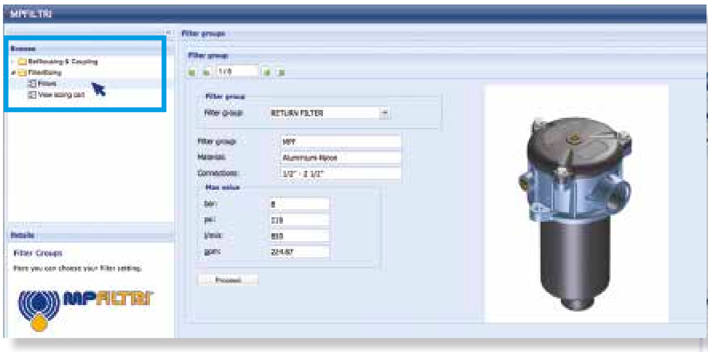
C.7 FHP Filter Series

High Pressure filters

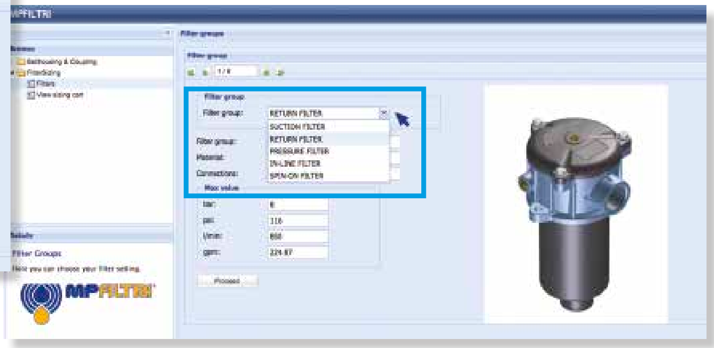
FHP series

Maximum working pressure up to 42 MPa (420 bar) - Flow rate up to 750 l/min

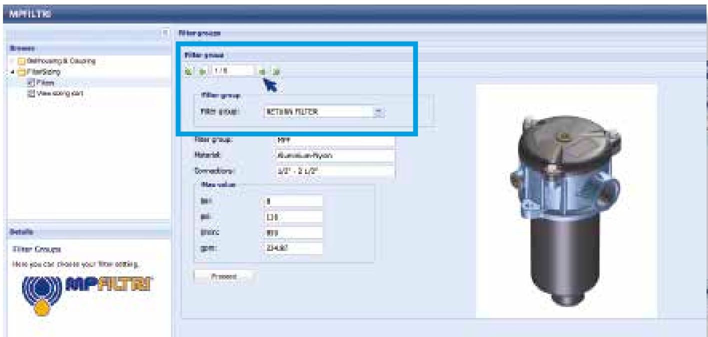
Step 1 Select "FILTERS"



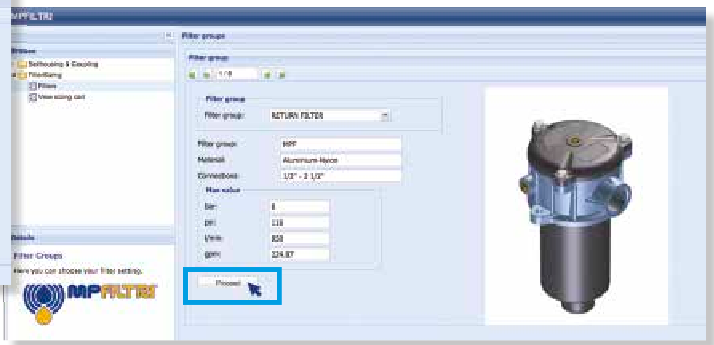
Step 2 Choose filter group (Return Filter, Pressure Filter, etc.)

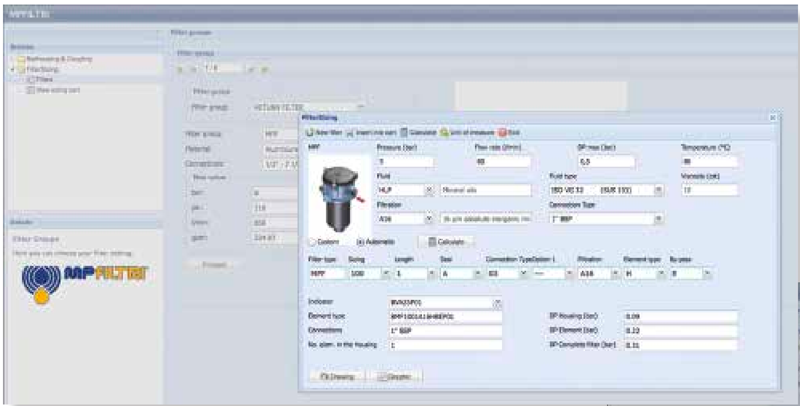


Step 3 Choose filter type (MPF, MPT, etc.) in function of the max working pressure and the max flow rate



Step 4 Push "PROCEED"





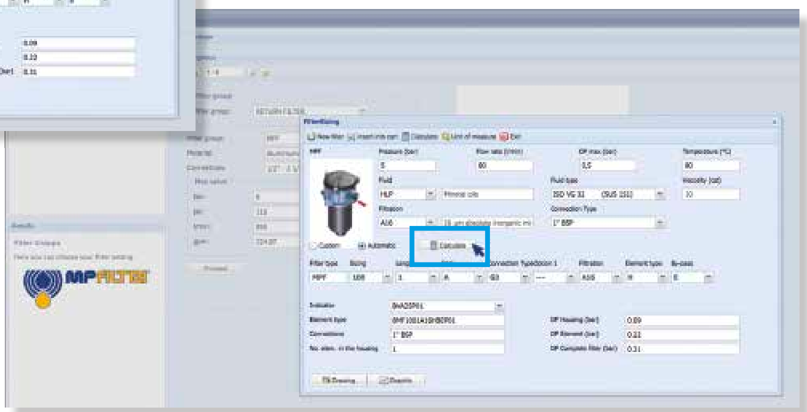
Step 5

Insert all application data to calculate the filter size following the sequence:

- working pressure
- working flow rate
- working pressure drop
- working temperature
- fluid material and fluid type
- filtration media
- connection type

Step 6

Push "CALCULATE" to have result; in case of any mistake, the system will advice which parameter is out of range to allow to modify/adjust the selection



Step 7

Download PDF

Datasheet "Report.aspx" pushing the button "Drawing"

FHP GENERAL INFORMATION

Description

High Pressure filters

In-line
Maximum working pressure up to 42 MPa (420 bar)
Flow rate up to 750 l/min

FHP is a range of versatile high pressure filter for protection of sensitive components in high pressure hydraulic systems in the industrial equipment.
They are directly connected to the lines of the system through the hydraulic fittings.

Available features:

- Female threaded connections up to 1 1/2" and flanged connections up to 2", for a maximum return flow rate of 750 l/min
- Fine filtration rating, to get a good cleanliness level into the system
- Bypass valve, to relieve excessive pressure drop across the filter media
- Check valve, to protect the system against reverse flow
- Reverse flow valve, to allow bidirectional flow through the filter housing. The back flow is not filtered. The filter requires the use of internal check valves to direct the flow through the element in one direction and around the element in the other
- Low collapse filter element "N", for use with filters provided with bypass valve
- High collapse filter element "H", for use with filters not provided with bypass valve
- Low collapse filter element with external support "R", for filter element protection against the back pressure caused by the check valve or the reverse flow in filters provided with the bypass valve
- High collapse filter element with external support "S", for filter element protection against the back pressure caused by the check valve or the reverse flow in filters not provided with the bypass valve
- Visual, electrical and electronic differential clogging indicators

Common applications:

Delivery lines, in any high pressure industrial equipment or mobile machines

Technical data

Filter housing materials

- Head: Phosphatized cast iron

- Housing: Phosphatized steel

- Bypass valve
  AISI 316L: FHP 010 - 011
  Brass: FHP 065 - 135
  Brass / AISI 304: FHP 350
  Steel: FHP 500

- Reverse Flow
  Steel: FHP 350 - FHP 500

- Check valve: Steel

Pressure

- Test pressure: 63 MPa (630 bar)
- Burst pressure: 126 MPa (1260 bar)
- Pulse pressure fatigue test: 1 000 000 cycles with pressure from 0 to 42 MPa (420 bar)

Bypass valve

- Opening pressure 600 kPa (6 bar) ±10%
- Other opening pressures on request.

Δp element type

- Microfibre filter elements - series N: 20 bar
- Microfibre filter elements - series R: 20 bar
  (not available for FHP 010-011 and FHP 500)
- Microfibre filter elements - series H: 210 bar
- Microfibre filter elements - series S: 210 bar (only for FHP 500)
- Wire mesh filter elements - series N: 20 bar
- Fluid flow through the filter element from OUT to IN

Seals

- Standard NBR series A
- Optional FPM series V

Temperature

From -25 °C to +110 °C

Connections

FHP 010 - 065 - 135 - 350 - 500:
In-line Inlet/Outlet
FHP 011:
90° Inlet/Outlet

Note

FHP filters are provided for vertical mounting

Weights [kg] and volumes [dm^3]

Filter series	Weights [kg]						Volumes [dm^3]					
	Length	1	2	3	4	5	Length	1	2	3	4	5
FHP 010 - 011		2.05	2.18	2.64	3.13	-		0.10	0.12	0.15	0.20	-
FHP 065		4.26	4.62	5.83	-	-		0.25	0.30	0.50	-	-
FHP 135		7.11	8.71	9.76	-	-		0.43	0.76	0.97	-	-
FHP 350		13.95	16.08	18.37	20.85	-		1.00	1.72	2.49	3.32	-
FHP 500		27.00	31.17	34.69	46.70	52.5		1.71	2.43	3.04	5.18	6.51

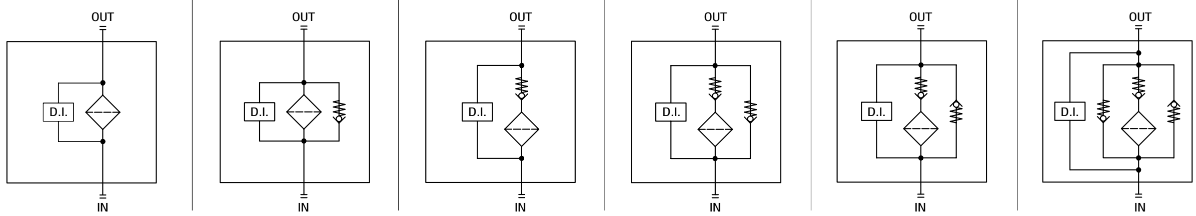
FILTER ASSEMBLY SIZING
Flow rates [l/min]

Filter series	Length	Filter element design - H Series					Filter element design - N Series					
		A03	A06	A10	A16	A25	A03	A06	A10	A16	A25	M25
FHP 010	**1**	3	5	6	7	8	4	6	8	9	10	37
	2	5	7	13	16	22	6	8	16	19	24	40
	3	10	13	22	25	30	11	14	23	26	31	41
	4	12	15	25	27	32	16	19	27	30	33	41
FHP 011	**1**	3	5	6	7	9	4	6	8	9	11	47
	2	5	7	14	17	24	7	9	17	21	28	52
	3	11	14	25	29	36	11	14	26	30	37	53
	4	12	16	28	32	38	17	21	32	36	40	54
FHP 065	**1**	24	25	50	59	84	25	33	56	63	90	142
	2	33	38	68	77	98	34	52	72	79	106	143
	3	61	70	100	107	123	61	73	101	108	125	147
FHP 135	**1**	49	55	95	98	147	67	72	115	122	159	184
	2	89	106	129	131	163	105	111	140	142	192	209
	3	120	132	158	166	180	141	143	176	179	193	211
FHP 350	**1**	108	115	188	197	301	127	140	234	282	343	451
	2	196	225	317	323	396	256	278	394	415	465	480
	3	266	310	384	392	440	331	370	450	466	475	490
	4	308	333	391	398	445	369	393	456	474	495	503
FHP 500	**1**	144	157	265	268	355	269	305	390	406	444	612
	2	232	262	350	363	398	321	357	433	441	484	619
	3	293	301	398	408	455	396	416	497	499	537	622
	4	336	377	452	455	507	430	475	516	524	545	626
	5	420	428	494	500	544	475	493	535	545	569	627

Maximum flow rate for a complete pressure filter with a pressure drop Δp = 1.5 bar.
The reference fluid has a kinematic viscosity of 30 mm^2/s (cSt) and a density of 0.86 kg/dm^3.
For different pressure drop or fluid viscosity we recommend to use our selection software available on www.mpfiltri.com.
You can also calculate the right size using the formulas present on the FILTER SIZING paragraph at the beginning of the full catalogue or at the beginning of the filter family brochure.
Please, contact our Sales Department for further additional information.

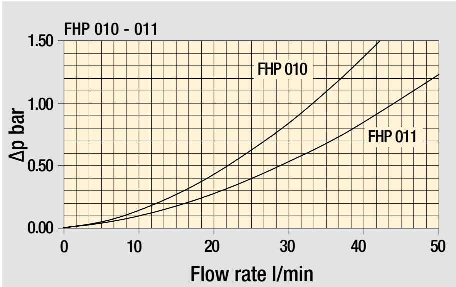
Hydraulic symbols

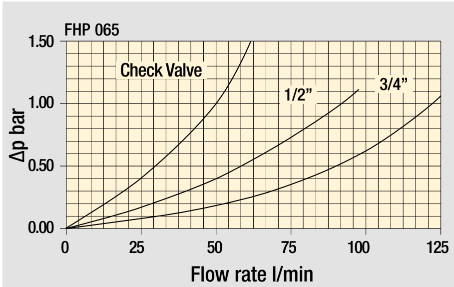
Filter series	Style S	Style B	Style T	Style D	Style V	Style Z
FHP 010 - 011	•	•			•	•
FHP 065	•	•	•			
FHP 135	•	•	•			
FHP 350	•	•	•	•	•	•
FHP 500	•	•	•	•	•	•

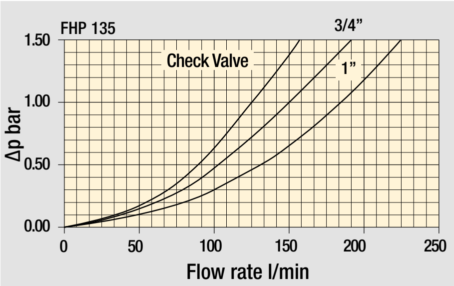


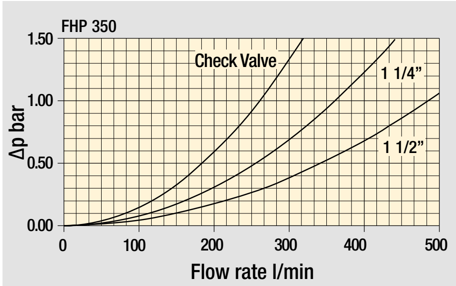
Pressure drop

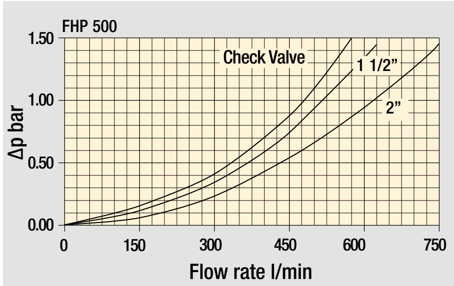
Filter housings Δp pressure drop



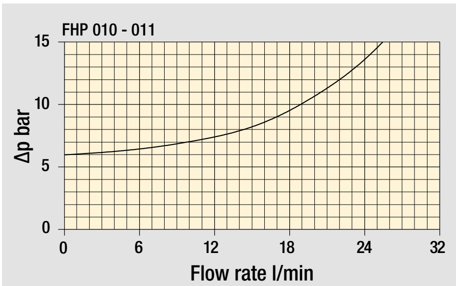


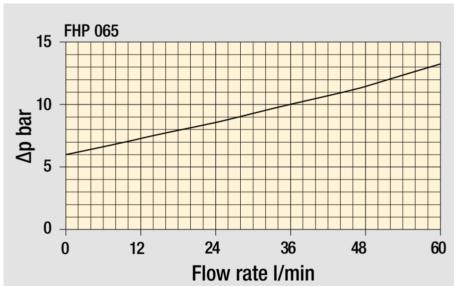


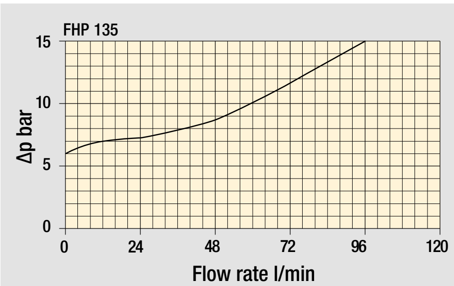


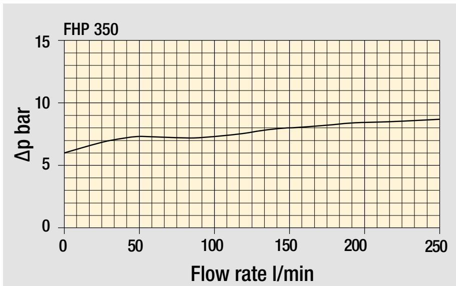


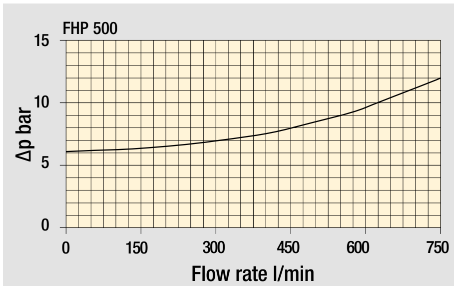
Bypass valve pressure drop



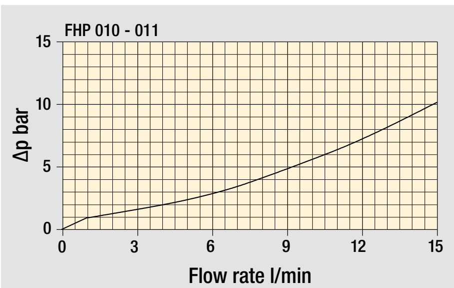




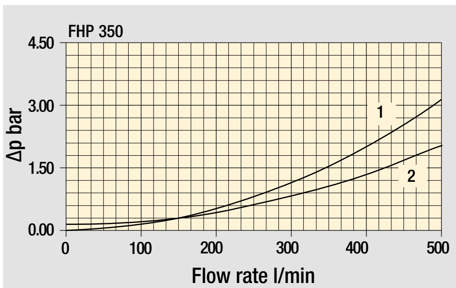




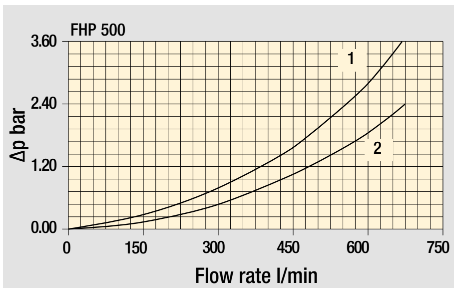
Valves



Filter housing with check valve



Pressure drop with reverse flow valve in
1 - Filtering direction
2 - Opposite direction



Pressure drop with reverse flow valve in
1 - Opposite direction
2 - Filtering direction

The curves are plotted using mineral oil with density of 0.86 kg/dm³ in compliance with ISO 3968. Δp varies proportionally with density.

Designation & Ordering code

COMPLETE FILTER

Configuration example: FHP010 | 2 | B | A | B | 2 | A03 | N | P01

Series and size

FHP010 | **FHP011**

Length

1 | **2** | **3** | **4**

Valves

S	Without bypass
B	With bypass 6 bar
V	With reverse flow, without bypass
Z	With reverse flow, with bypass 6 bar

Seals

A	NBR
V	FPM

Connections

A	G 1/4"
B	1/4" NPT
C	SAE 5 - 1/2" - 20 UNF
D	G 3/8"
E	3/8" NPT
F	SAE 6 - 9/16" - 18 UNF

Connection for differential indicator

1	Without
2	With connection

Filtration rating (filter media)

A03	Inorganic microfiber	3 μm	**A16**	Inorganic microfiber	16 μm
A06	Inorganic microfiber	6 μm	**A25**	Inorganic microfiber	25 μm
A10	Inorganic microfiber	10 μm	**M25**	Wire mesh	25 μm

Element Δp		Valves S	Valves B	Valves V	Valves Z
N	20 bar		•		•
H	210 bar	•		•	

Execution

P01	MP Filtri standard
Pxx	Customized

FILTER ELEMENT

Configuration example: HP011 | 2 | A03 | A | N | P01

Element series and size

HP011

Element length

1 | **2** | **3** | **4**

Filtration rating (filter media)

A03	Inorganic microfiber	3 μm	**A16**	Inorganic microfiber	16 μm
A06	Inorganic microfiber	6 μm	**A25**	Inorganic microfiber	25 μm
A10	Inorganic microfiber	10 μm	**M25**	Wire mesh	25 μm

Seals

A	NBR
V	FPM

Element Δp

N	20 bar
H	210 bar

Execution

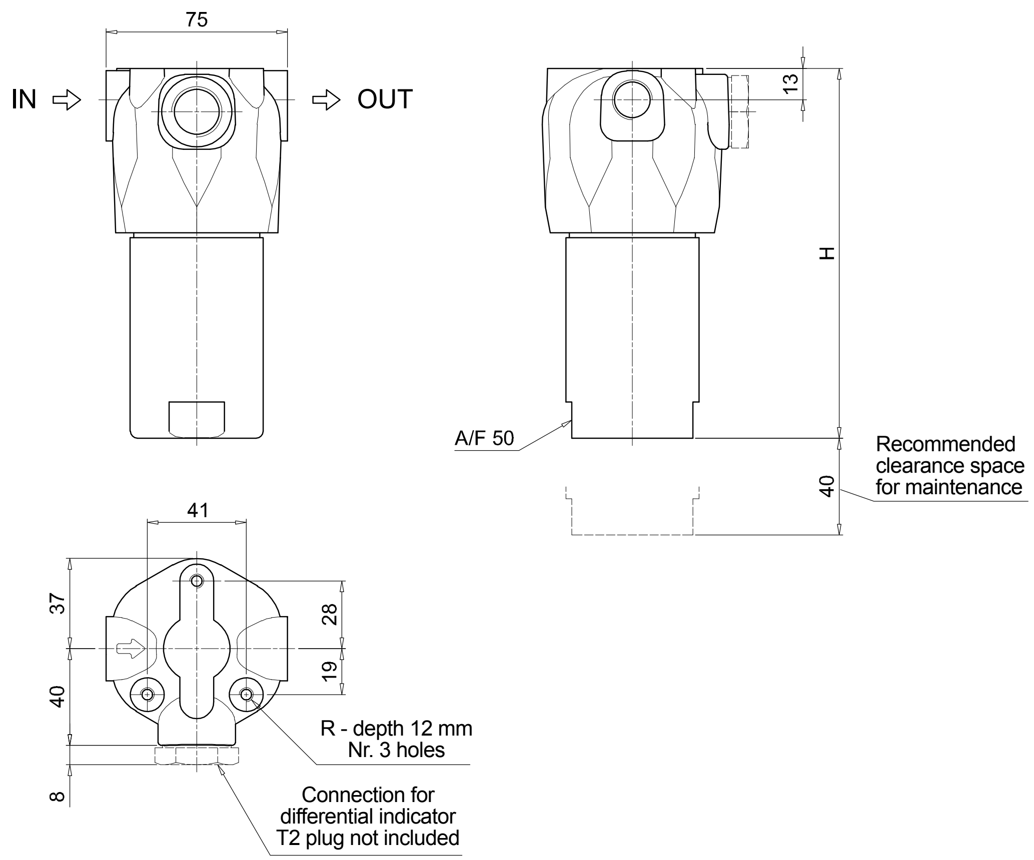
P01	MP Filtri standard
Pxx	Customized

ACCESSORIES

Differential indicators		page
DEA	Electrical differential indicator	567
DEH	Hazardous area electronic differential indicator	567-568
DEM	Electrical differential indicator	568-569
DLA	Electrical / visual differential indicator	569-570
DLE	Electrical / visual differential indicator	570
DTA	Electronic differential indicator	571
DVA	Visual differential indicator	571
DVM	Visual differential indicator	571

Additional features		page
T2	Plug	572

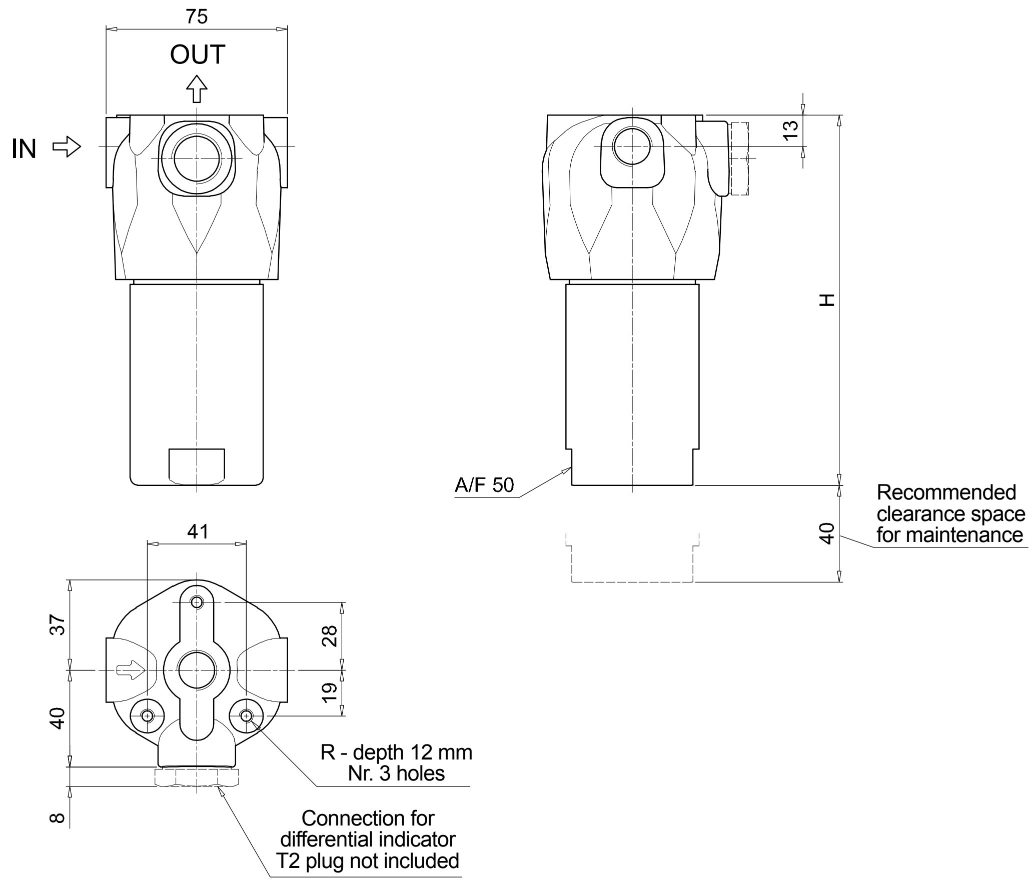
Dimensions



FHP010

Filter length	H [mm]
1	92
2	103
3	153
4	203

Connections	R
A	M6
B - C	1/4" UNC
D	M6
E - F	1/4" UNC



FHP011

Filter length	H [mm]
1	92
2	103
3	153
4	203

Connections	R
A	M6
B - C	1/4" UNC
D	M6
E - F	1/4" UNC

Designation & Ordering code

COMPLETE FILTER

Configuration example: FHP135 | 2 | B | A | G3 | A06 | S | P01

Series and size

FHP065 | **FHP135**

Length

1	
2	
3	

Valves

S	Without bypass
B	With bypass 6 bar
T	With check valve, without bypass

Seals

A	NBR
V	FPM

Connections	FHP065	FHP135
G1	G 1/2”	G 3/4”
G2	G 3/4”	G 1”
G3	1/2” NPT	3/4” NPT
G4	3/4” NPT	1” NPT
G5	SAE 8 - 3/4” - 16 UNF	SAE 12 - 1 1/16” - 12 UN
G6	SAE 12 - 1 1/16” - 12 UN	SAE 16 - 1 5/16” - 12 UN
F1	-	3/4” SAE 3000 psi/M
F2	-	1” SAE 3000 psi/M
F3	-	3/4” SAE 3000 psi/UNC
F4	-	1” SAE 3000 psi/UNC
F5	-	3/4” SAE 6000 psi/M
F6	-	3/4” SAE 6000 psi/UNC

Filtration rating (filter media)

A03	Inorganic microfiber	3 μm
A06	Inorganic microfiber	6 μm
A10	Inorganic microfiber	10 μm
A16	Inorganic microfiber	16 μm
A25	Inorganic microfiber	25 μm
M25	Wire mesh	25 μm

Element Δp		Valves S	B	T	D	V	Z
N	20 bar		•				
R	20 bar				•		•
H	210 bar	•					
S	210 bar			•		•	

Execution

P01	MP Filtri standard
Pxx	Customized

FILTER ELEMENT

Configuration example: HP135 | 2 | A06 | A | S | P01

Element series and size

HP065 | **HP135**

Element length

1	
2	
3	

Filtration rating (filter media)

A03	Inorganic microfiber	3 μm
A06	Inorganic microfiber	6 μm
A10	Inorganic microfiber	10 μm
A16	Inorganic microfiber	16 μm
A25	Inorganic microfiber	25 μm
M25	Wire mesh	25 μm

Seals

A	NBR
V	FPM

Element Δp

N	20 bar
R	20 bar
H	210 bar
S	210 bar

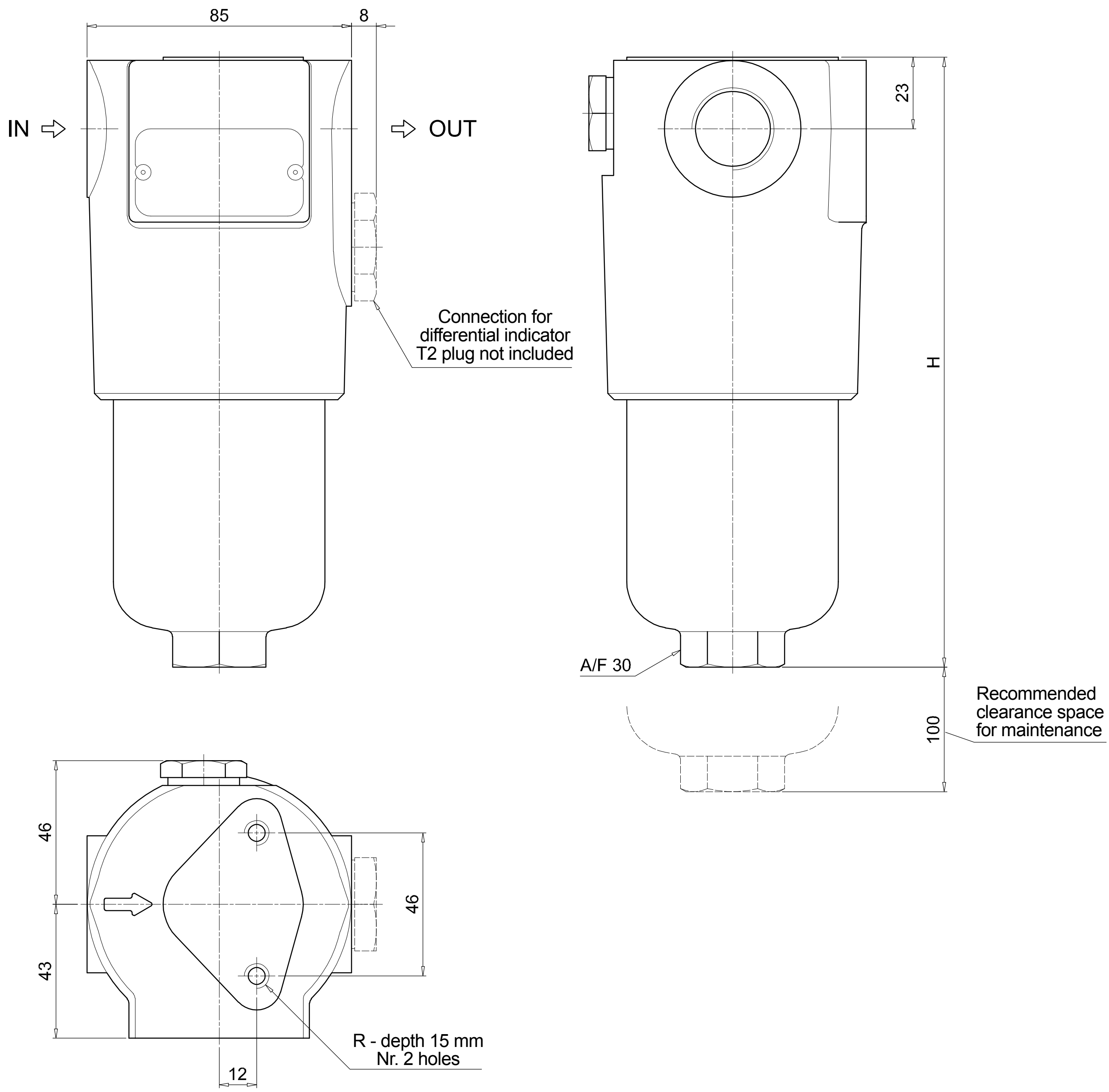
Execution

P01	MP Filtri standard
Pxx	Customized

ACCESSORIES

Differential indicators		page
DEA	Electrical differential indicator	567
DEH	Hazardous area electronic differential indicator	567-568
DEM	Electrical differential indicator	568-569
DLA	Electrical / visual differential indicator	569-570
DLE	Electrical / visual differential indicator	570
DTA	Electronic differential indicator	571
DVA	Visual differential indicator	571
DVM	Visual differential indicator	571

Additional features		page
T2	Plug	572

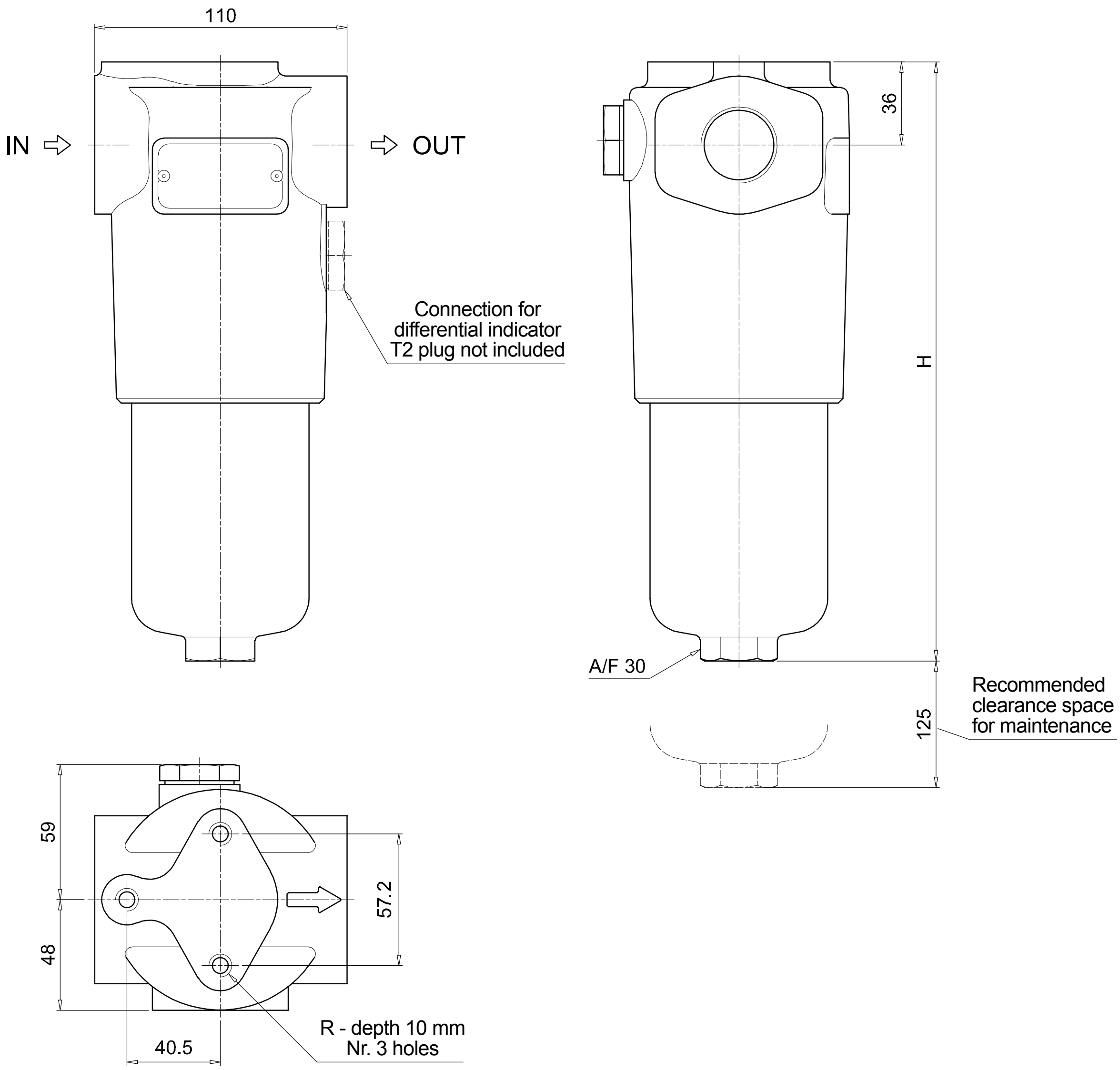


FHP065

Filter length	H [mm]
1	196
2	227
3	329

Connections	R
G1-G2	M8
G3-G4-G5-G6	5/16" UNC

Dimensions



FHP135

Filter length	H [mm]
1	260
2	373
3	448

Connections	R
G1-G2	M10
G3-G4-G5-G6	3/8” UNC
F1-F2	M10
F3-F4	3/8” UNC
F5	M10
F6	3/8” UNC

Designation & Ordering code

COMPLETE FILTER

Configuration example: FHP350 | 4 | B | A | D | 2 | A06 | N | P01

Series and size
FHP350

Length
1 | **2** | **3** | **4**

Valves

S	Without bypass
B	With bypass 6 bar
T	With check valve, without bypass
D	With check valve, with bypass 6 bar
V	With reverse flow, without bypass
Z	With reverse flow, with bypass 6 bar

Seals

A	NBR
V	FPM

Connections

A	G 1 1/2”
B	1 1/2” NPT
C	SAE 24 - 1 7/8” - 12 UN
D	1 1/2” SAE 3000 psi/M + G 1 1/4”
E	1 1/2” SAE 3000 psi/UNC + 1 1/4” NPT
F	1 1/2” SAE 3000 psi/UNC + SAE 20 - 1 5/8” - 12 UN
G	1 1/4” SAE 3000 psi/M
H	1 1/4” SAE 3000 psi/UNC
I	1 1/4” SAE 6000 psi/M
L	1 1/4” SAE 6000 psi/UNC

Connection for differential indicator

2	With connection

Filtration rating (filter media)

A03	Inorganic microfiber	3 µm
A06	Inorganic microfiber	6 µm
A10	Inorganic microfiber	10 µm
A16	Inorganic microfiber	16 µm
A25	Inorganic microfiber	25 µm
M25	Wire mesh	25 µm

Element Δp		Valves S	B	T	D	V	Z
N	20 bar		•				
R	20 bar				•		•
H	210 bar	•					
S	210 bar			•		•	

Execution		Filter length 1	2	3	4
P01	MP Filtri standard	•	•	•	•
P02	Maintenance from the bottom of the housing				•
Pxx	Customized				

FILTER ELEMENT

Configuration example: HP320 | 4 | A06 | A | N | P01

Element series and size
HP320

Element length
1 | **2** | **3** | **4**

Filtration rating (filter media)

A03	Inorganic microfiber	3 µm
A06	Inorganic microfiber	6 µm
A10	Inorganic microfiber	10 µm
A16	Inorganic microfiber	16 µm
A25	Inorganic microfiber	25 µm
M25	Wire mesh	25 µm

Seals	
A	NBR
V	FPM

Element Δp	
N	20 bar
R	20 bar
H	210 bar
S	210 bar

Execution	
P01	MP Filtri standard
Pxx	Customized

ACCESSORIES

Differential indicators		page
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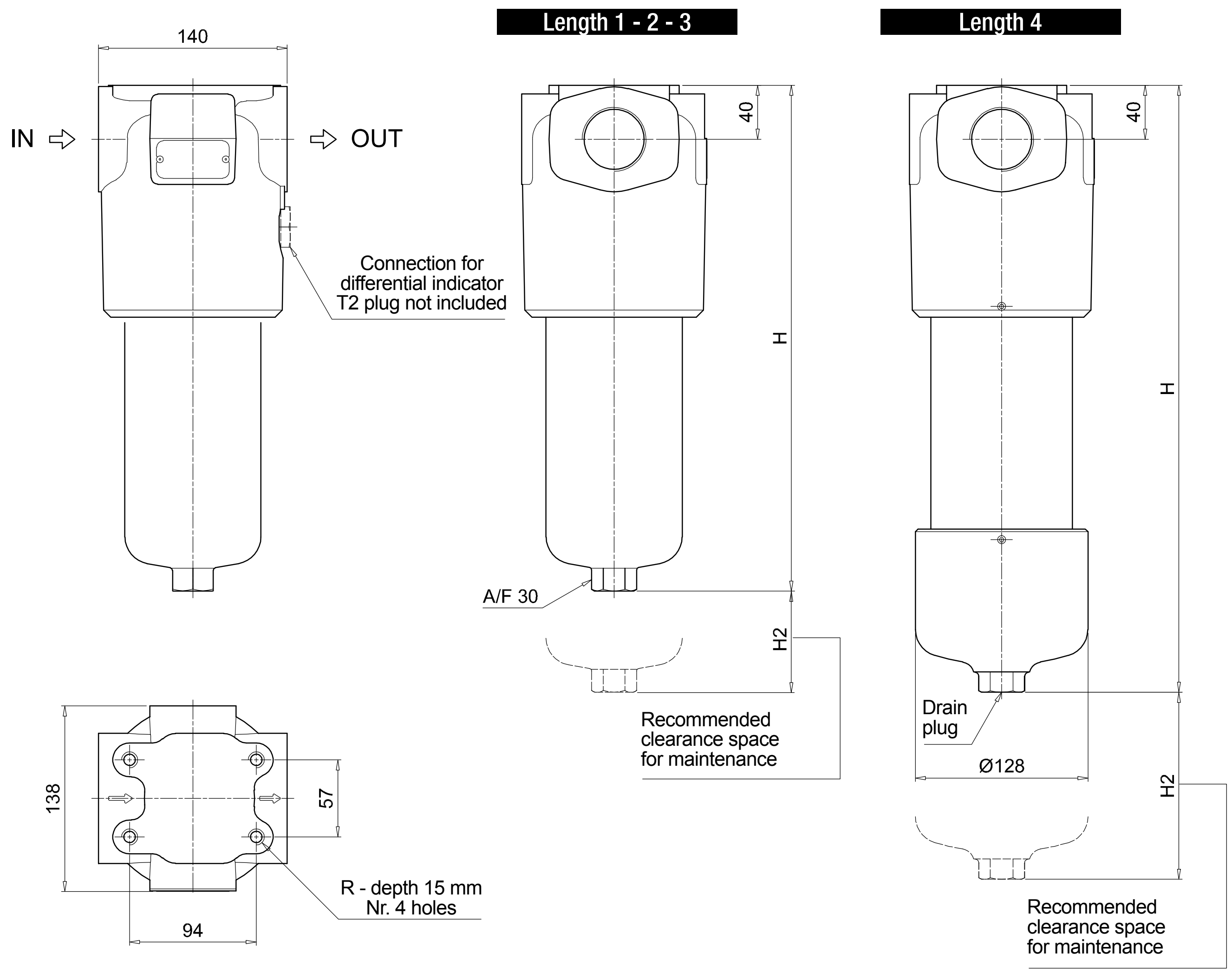
DEM	Electrical differential indicator	568-569
DLA	Electrical / visual differential indicator	569-570
DLE	Electrical / visual differential indicator	570
DTA	Electronic differential indicator	571
DVA	Visual differential indicator	571
DVM	Visual differential indicator	571

Additional features		page
T2	Plug	572



FHP350

Filter length	H [mm]	H2 [mm] Execution P01	P02
1	295	150	-
2	418	150	-
3	550	150	-
4	703	150	550

Connections	R
A	M12
B - C	1/2" UNC
D	M12
E - F	1/2" UNC
G	M12
H	1/2" UNC
I	M12
L	1/2" UNC

Designation & Ordering code

COMPLETE FILTER

Configuration example: FHP500 | 4 | V | A | G1 | A06 | S | P01

Series and size

FHP500

Length

1 | 2 | 3 | 4 | 5

Valves	
S	Without bypass
B	With bypass 6 bar
T	With check valve, without bypass
D	With check valve, with bypass 6 bar
V	With reverse flow, without bypass
Z	With reverse flow, with bypass 6 bar

Seals	
A	NBR
V	FPM

Connections			
G1	G 1 1/2”	**F4**	2” SAE 3000 psi/UNC
G2	1 1/2” NPT	**F5**	1 1/2” SAE 6000 psi/M
G3	SAE 24 - 1 7/8” - 12 UN	**F6**	1 1/2” SAE 6000 psi/UNC
F1	1 1/2” SAE 3000 psi/M	**F7**	2” SAE 6000 psi/M
F2	1 1/2” SAE 3000 psi/UNC	**F8**	2” SAE 6000 psi/UNC
F3	2” SAE 3000 psi/M		

Filtration rating (filter media)		
A03	Inorganic microfiber	3 μm
A06	Inorganic microfiber	6 μm
A10	Inorganic microfiber	10 μm
A16	Inorganic microfiber	16 μm
A25	Inorganic microfiber	25 μm
M25	Wire mesh	25 μm

Element Δp		Valves S	B	T	D	V	Z
N	20 bar		•				
R	20 bar				•		•
S	210 bar	•		•		•	

Execution		Filter length 1	2	3	4	5
P01	MP Filtri standard	•	•	•	•	•
P02	Maintenance from the bottom of the housing				•	•
P03	Drain plug	•	•			
Pxx	Customized	•	•	•	•	•

FILTER ELEMENT

Configuration example: HP500 | 4 | A06 | A | S | P01

Element series and size

HP500

Element length

1 | 2 | 3 | 4 | 5

Filtration rating (filter media)		
A03	Inorganic microfiber	3 μm
A06	Inorganic microfiber	6 μm
A10	Inorganic microfiber	10 μm
A16	Inorganic microfiber	16 μm
A25	Inorganic microfiber	25 μm
M25	Wire mesh	25 μm

Seals	
A	NBR
V	FPM

Element Δp	
N	20 bar
R	20 bar
S	210 bar

Execution	
P01	MP Filtri standard
Pxx	Customized

ACCESSORIES

Differential indicators		page
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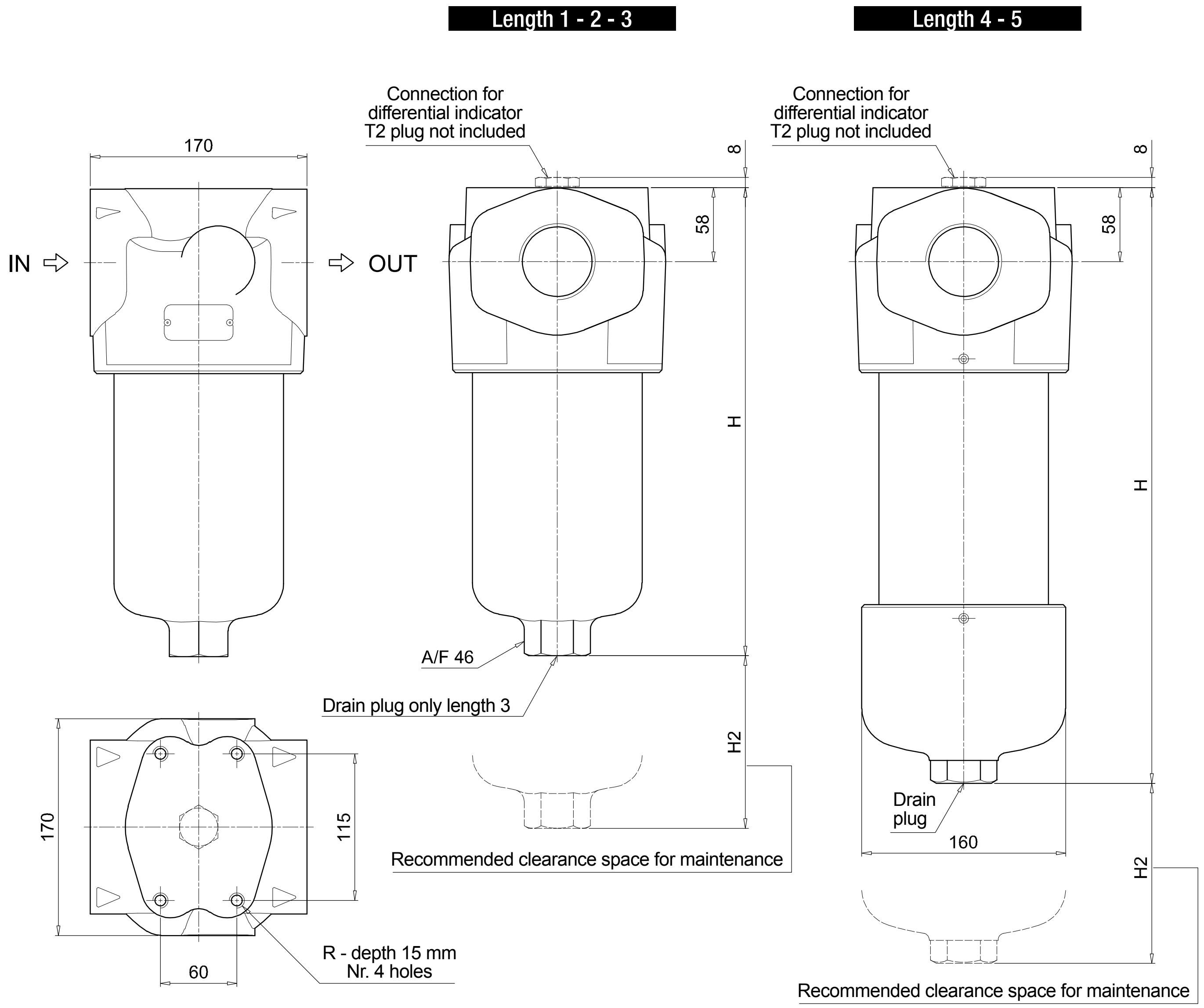
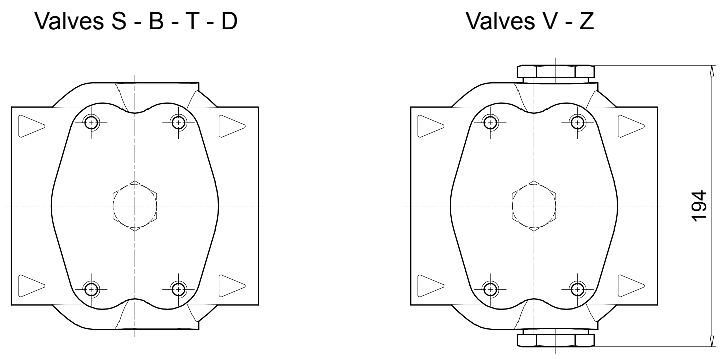
DEM	Electrical differential indicator	568-569
DLA	Electrical / visual differential indicator	569-570
DLE	Electrical / visual differential indicator	570
DTA	Electronic differential indicator	571
DVA	Visual differential indicator	571
DVM	Visual differential indicator	571

Additional features		page
T2	Plug	572

Dimensions





FHP500

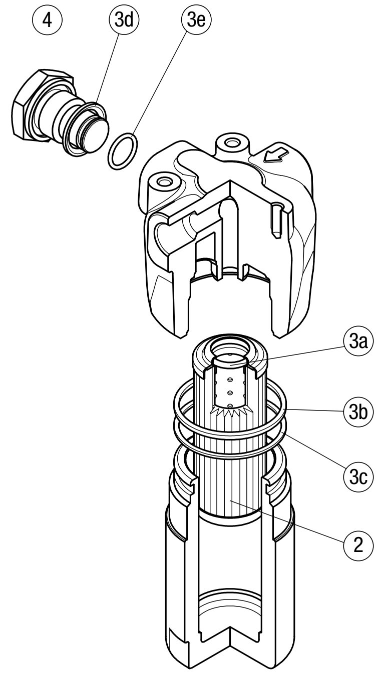
Filter length	H [mm]	H2 [mm] Execution P01	P02
1	330	150	-
2	420	150	-
3	496	150	-
4	654	150	480
5	820	150	650

Connections	R
G1	M12
G2-G3	1/2" UNC
F1	M12
F2	1/2" UNC
F3	M12
F4	1/2" UNC
F5	M12
F6	1/2" UNC
F7	M12
F8	1/2" UNC

FHP SPARE PARTS

Order number for spare parts

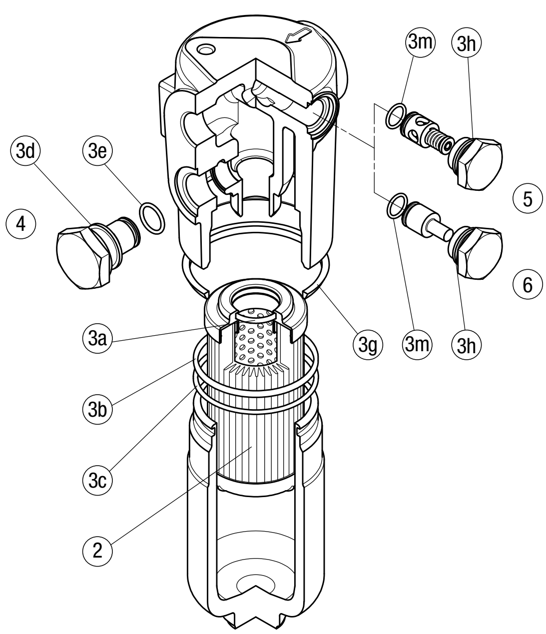
FHP 010 - 011



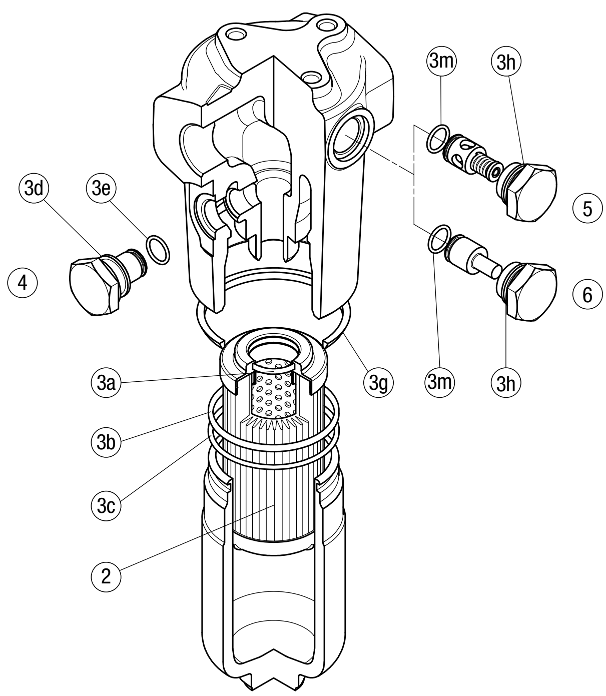
Q.ty:
nr. 0 pcs. for version 1 (without indicator port)
nr. 1 pc. for version 2 (with indicator port)

Item:	Q.ty: 1 pc. 2	Q.ty: 1 pc. 3 (3a ÷ 3e)		4	
Filter series	Filter element	Seal Kit code number NBR	Seal Kit code number FPM	Indicator connection plug NBR	Indicator connection plug FPM
FHP 010-011	See order table	02050501	02050492	T2H	T2V

FHP 065



FHP 135

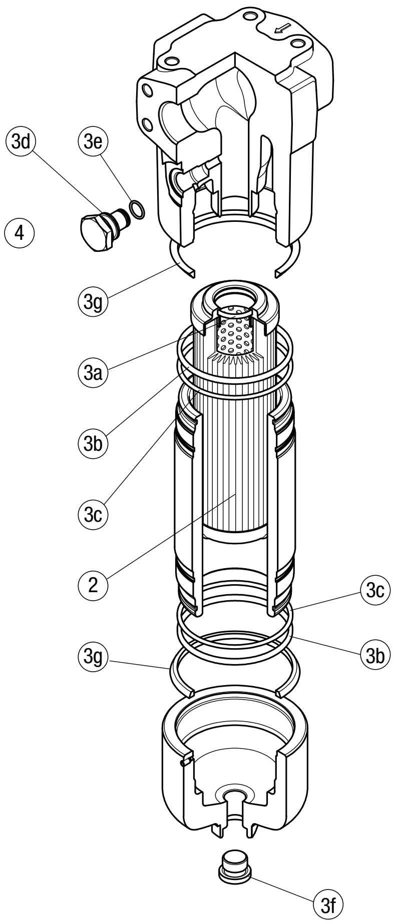


Item:	Q.ty: 1 pc. 2	Q.ty: 1 pc. 3 (3a ÷ 3m)		Q.ty: 1 pc. 4		Q.ty: 1 pc. 5		Q.ty: 1 pc. 6	
Filter series	Filter element	Seal Kit code number NBR	Seal Kit code number FPM	Indicator connection plug NBR	Indicator connection plug FPM	Bypass assembly NBR	Bypass assembly FPM	Non-bypass assembly NBR	Non-bypass assembly FPM
FHP 065	See order table	02050265	02050276	T2H	T2V	02001116	02001136	02001142	02001139
FHP 135		02050269	02050280			02001117	02001137	02001143	02001392

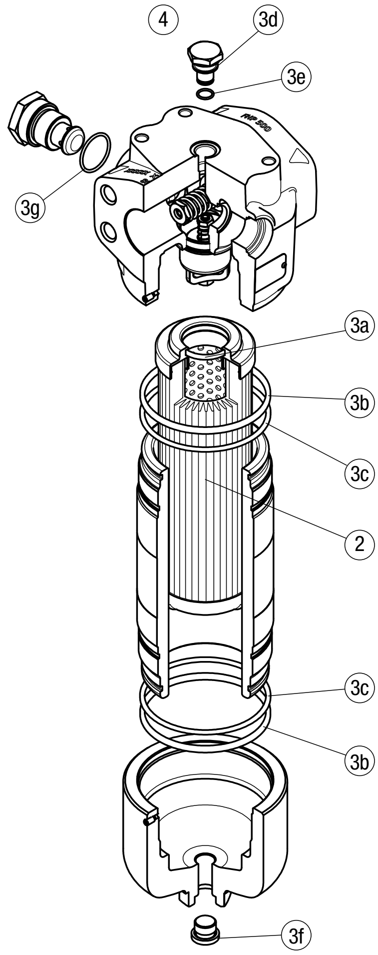
SPARE PARTS FHP

Order number for spare parts

FHP 350



FHP 500

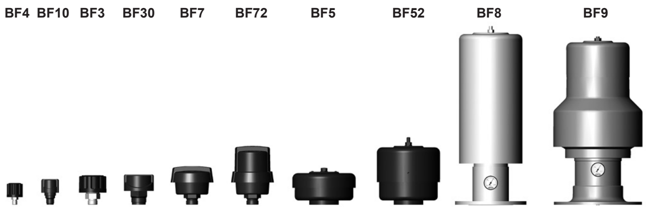


Item:	Q.ty: 1 pc. 2	Q.ty: 1 pc. 3 (3a ÷ 3g for FHP 350) (3a ÷ 3f for FHP 500)		Q.ty: 1 pc. 4	
Filter series	Filter element	Seal Kit code number NBR	FPM	Indicator connection plug NBR	FPM
FHP 350	See order table	02050272	02050283	T2H	T2V
FHP 500		02050330	02050331		

C.8 Tank Breathing Filter

HYDAC INTERNATIONAL

Tank Breather Filter BF
up to 11000 l/min



1. TECHNICAL SPECIFICATIONS

1.1 FILTER HOUSING

Construction

Breather filter sizes 4, 10, 3 and 30 consist of a housing which is screwed onto the oil tank, and a built-in filter element.

Sizes 5, 52, 7 and 72 have housings which are screwed onto the oil tank and have one or two exchangeable filter element(s).

BF 5 and 52 are fitted with a built-in oil mist trap as standard.

Sizes 8 and 9 consist of a flange for mounting to the tank, an exchangeable element and a cap. The BF 9 also has an oil mist trap which allows the oil to be drained via an oil drain plug.

1.2 FILTER ELEMENTS

HYDAC filter elements are validated and their quality is constantly monitored according to the following standards:

- ISO 2941
- ISO 2942
- ISO 2943
- ISO 3724
- ISO 3968
- ISO 11170
- ISO 16889

Contamination retention capacities in g

	Paper
BF	3 µm
4	2.9
10	2.9
3	6.2
30	6.2
7	26.1
72	52.2
5	85.1
52	170.2

The filter elements are made from phenolic resin-impregnated paper and cannot therefore

1.3 FILTER SPECIFICATIONS

Temperature range	-30 °C to +100 °C
Material of housing	Steel, zinc-plated/plastic coated (BF 4, 3), Steel (BF 5, 52) Steel, galvanized (BF 8) Aluminium (BF 9) Glass fibre reinforced plastic (BF 10, 30, 7, 72)
Type of clogging indicator	VMF (pressure gauge)
Pressure setting of clogging indicator	0.6 bar K pressure gauge 0.035 bar UBM indicator (others on request)

1.4 SEALS

NBR (= Perbunan) on filter
Polyurethane on element
Cardboard on mounting flange

1.5 SPECIAL MODELS AND ACCESSORIES

- with check/bypass valve to support the suction characteristics of the pump
  Not 100% air-tight or leakage-free!
  (only BF 10 (except for G¼), 3, 30, 5 and 52)
- with anti-splash device
  (only BF 10, 3, 30, 7, 72)
- with connection for a clogging indicator
  (only BF 7, 72, 8, 9)
- with manual pressure release
  (= BFPR; only BF 10)

1.6 SPARE PARTS

See Original Spare Parts List

1.7 CERTIFICATES, APPROVALS, STANDARDS

BF 7, 72 to Renault standard;
others on request

1.8 COMPATIBILITY WITH HYDRAULIC FLUIDS ISO 2943

The standard models are suitable for use with mineral and lubrication oils.
For fire-resistant and biodegradable oils, see tables:

Fire-resistant fluids

BF	HFA	HFC	HFD-R
4, 3, 5, 52	–	–	–
10, 30, 7, 72	●	●	–
8, 9	●	●	●

- HFA oil in water emulsion
  (H_2O content ≥ 80%)

Biodegradable fluids

BF	HTG	HE	HPG	
			PAG	PRG
4, 10, 3, 30	+	+	●	●
7, 72, 5, 52	+	+	●	●
8, 9	+	+	●	●

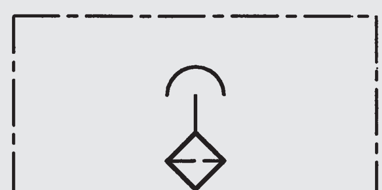
+ suitable for all
● contact our Technical Sales Department
– not suitable

- HTG vegetable oil based operating fluids
- HE ester-based synthetic hydraulic fluids
- HPG polyglycol-based synthetic hydraulic fluids
- PAG sub-group of HPG: polyalkylene glycol
- PEG sub-group of HPG: polyethylene glycol

1.9 CHANGING INTERVALS

The filter elements or filters must be replaced as frequently as the fluid filters, but at least every 12 months.

Symbol



2. MODEL CODE (also order example)

2.1 COMPLETE FILTER

2.1.1 BF 4 and 3

BF P 3 G 3 W 4 . X /-RV

Filter type
BF

Filter material
P Paper

Size of filter
BF 4, 3

Type and size of connection

Des.	Type	Connection	Filter size BF4	Filter size BF3
G	Thread ISO 228	G ¼	•	
		G ½		•
		G ¾		•
		G 3/8		•

Filtration rating in µm
P 3 (absolute)

Type of clogging indicator
W without port, no clogging indicator

Type code

Size	Code	Connection	Δp [bar]
BF 3	1.X	G ¾	-
BF 3	2.X	G 3/8	-
BF 3	3.X	G ½	-
BF 3../-RV	4.X	G ¾	0.4
BF 3../-RV	5.X	G ¾	0.7
BF 3../-RV	6.X	G ¾	0.2
BF 3../-RV	7.X	G ¾	1.0
BF 4	1.X	G ¼	-

Modification number
X the latest version is always supplied

Supplementary details
RV check/bypass valve (not for BF 4)

2.1.2 BF 10 and 30

BF P 30 G 3 W 1 . X /-RV0.2

Filter type
BF

Filter material
P Paper

Size of filter
BF 10, 30

Type and size of connection

Des.	Type	Connection	Filter size BF10	Filter size BF30
G	thread ISO 228	G ¼	•	
		G 3/8	•	
		G ¾		•
M	metr. connection	M 42x2		•
		M 30x1.5		•
		M 22x1.5	•	
N	NPT thread	½	•	
		¾		•
U	UNF thread	1 1/16-12UN-2A	•	•

Filtration rating in µm
P 3 (absolute)

Type of clogging indicator
W without port, no clogging indicator

Type code

Size	Code	Connection
BF 30 G…	1.X	G ¾
BF 30 M…	1.X	M 42x2
BF 30 M...	2.X	M 30x1.5
BF 30 N...	1.X	NPT ¾
BF 30 U...	1.X	1 1/16-12UN-2A
BF 10 G...	1.X	G ¼
BF 10 G...	2.X	G 3/8
BF 10 M...	1.X	M 22x1.5
BF 10 N...	1.X	NPT ½
BF 10 U...	3.X	1 1/16-12UN-2A

Modification number
X the latest version is always supplied

Supplementary details
AS anti-splash without check/bypass valve
RV0.2, RV0.4, RV0.7 valve with relevant pressure setting (not for BF 10 with G 1/4)

2.1.3 BF 7 and 72

BF P 72 G 3 W 1 . X /-AS

Filter type
BF

Filter material
P Paper

Size
BF 7, 72

Type and size of connection

Des.	Type	Connection	Filter size 7	Filter size 72
G	Thread ISO 228	G 1	•	•
N	NPT-Thread	3/4	•	•
U	UNF-Thread	G 1 5/16-12UN	•	•
M	metric connection	M30 x 1.5	•	•

Filtration rating in µm
P 3 (absolute)

Type of clogging indicator
W without port, no clogging indicator
K pressure gauge (measuring range -1 to +0.6 bar) (not for BF 72)
UBM visual/analogue vacuum gauge with manual reset (pressure setting: -0.035 bar)

Type code
1

Modification number
X the latest version is always supplied

Supplementary details
AS anti-splash device (not for model with K pressure gauge)

2.1.4 BF 5 and 52

BF P 52 G 3 W 1 . X /-RV0.4

Filter type
BF

Filter material
P Paper
BN Betamicron®

Size of filter
BF 5, 52

Type and size of connection

Des.	Type	Conn.	Filter size 5	Filter size 52
G	Thread ISO 228	G 2½	•	•
N	NPT-Thread	2½	•	•

Filtration rating in µm
BN 3, 10 (absolute)
P 3 (absolute)

Type of clogging indicator
W without port, no clogging indicator

Type code
1

Modification number
X the latest version is always supplied

Supplementary details
RV0.4 check/bypass valve with 0.4 bar pressure setting
SO479 filter suitable for HFC fluids

2.1.5 BF 8 and 9

BF BN 8 F 1 A 1 . X

Filter type
BF

Filter material
BN Betamicron®
BN/AM Betamicron®/Aquamicron®

Size of filter
BF 8, 9

Type and size of connection

Des.	Type	Filter size 8	Filter size 9
F	Flange	•	•

Filtration rating in µm
BN 1, 2 for BF 8
BN 2 for BF 9
BN/AM 1 for BF 8

Type of clogging indicator
A blanking plug in indicator port
K pressure gauge (measuring range -1 to +0.6 bar)

Type code
1

Modification number
X the latest version is always supplied

2.2 REPLACEMENT ELEMENT

0005 L 003 P

Size
0005 for BF 5, 52 (on BF 52: 2 x 0005 L...)
0007 for BF 7
0072 for BF 72
0008 for BF 8
0009 for BF 9

Type
L

Filtration rating in µm
P: 003 (BF 5, 52, 7, 72)
BN: 001, 002 (BF 8)
BN: 002 (BF 9)
BN: 003, 010 (BF 5, 52)
BN4AM: 001 (BF 8)

Filter material
P Paper (BF 5, 52, 7, 72)
BN Betamicron® (BF 5, 52, 8, 9)
BN4AM Betamicron®/Aquamicron® (BF 8)

Replacement elements cannot be ordered for BF 4, 10, 3, 30. These filters are only available complete!

2.3 REPLACEMENT CLOGGING INDICATOR

VMF 0.6 K . X

Type
VMF Return line indicator

Pressure setting
0.6 -1 to +0.6 bar
0.035 -0.035 bar

Type
A blanking plug in indicator port
K pressure gauge (pressure setting -1 to +0.6 bar)
UBM visual-analogue vacuum gauge with manual reset (pressure setting: -0.035 bar)

Modification number
X the latest version is always supplied

2.4 MODEL CODE FOR BF 7 AND 72 TO RENAULT SPECIFICATION

BF P 7 F 3 UBM 0 . X

Size
7 Tank volume from 20 to 400 litres
72 Tank volume over 400 litres

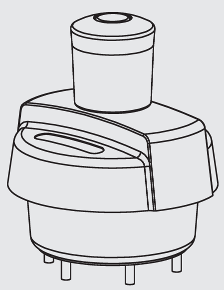
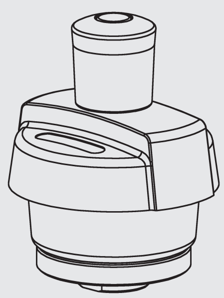
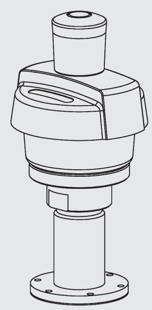
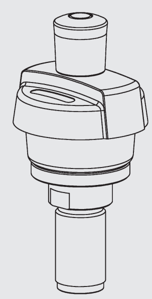
Type and size of connection

Des.	Type	Filter size 7	Filter size 72
G	with threaded adapter	•	•
F	with flange adapter	•	•
S	with weld adapter	•	•

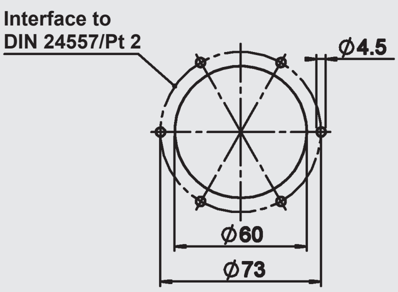
Type of clogging indicator
UBM visual analogue vacuum pressure gauge with manual reset, measuring range 0 to +0.035 bar

Type code (TKZ)
0 without adapter (basic model)
2 incl. adapter with male thread G ¾
3 incl. adapter with female thread 1½-16 UNC
4 incl. adapter with female thread G ¾
5 incl. flange adapter (1½-16 UNC)
6 incl. flange adapter (G ¾)
7 incl. weld adapter (1½-16 UNC)
8 incl. weld adapter (G ¾)
9 incl. adapter with male thread G 1¼

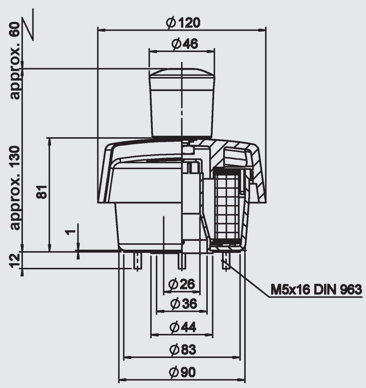
Modification number
X the latest version is always supplied
EFS Filling protection

Basic model	With threaded adapter	With flange adapter	With weld adapter
			

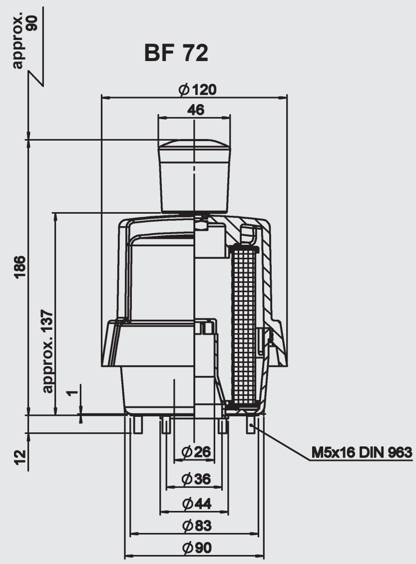
Dimensions BF 7/72 to RENAULT specification



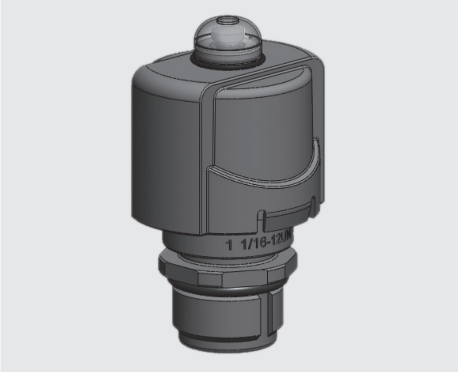
BF 7



BF 72



For further information on the BF7/72 to Renault specification please contact HYDAC.



TECHNICAL DESCRIPTION

Breather filters with manual pressure release "BFPR" consist of a housing which is screwed onto the oil tank and which has an integrated air filter element.

An integrated valve allows the oil tank to be pressurized to different pressures, for example to support the pump during start-up, thereby avoiding cavitation of the pump.

The manual pressure release function enables complete pressure release which is initiated when the pressure release button is pressed. This pressure release is required for example before carrying out maintenance on the tank and connecting pipes or hoses, to prevent potential accidents or injury by opening a pressurised system.

CAUTION:
This filter must not be used as a safety valve!

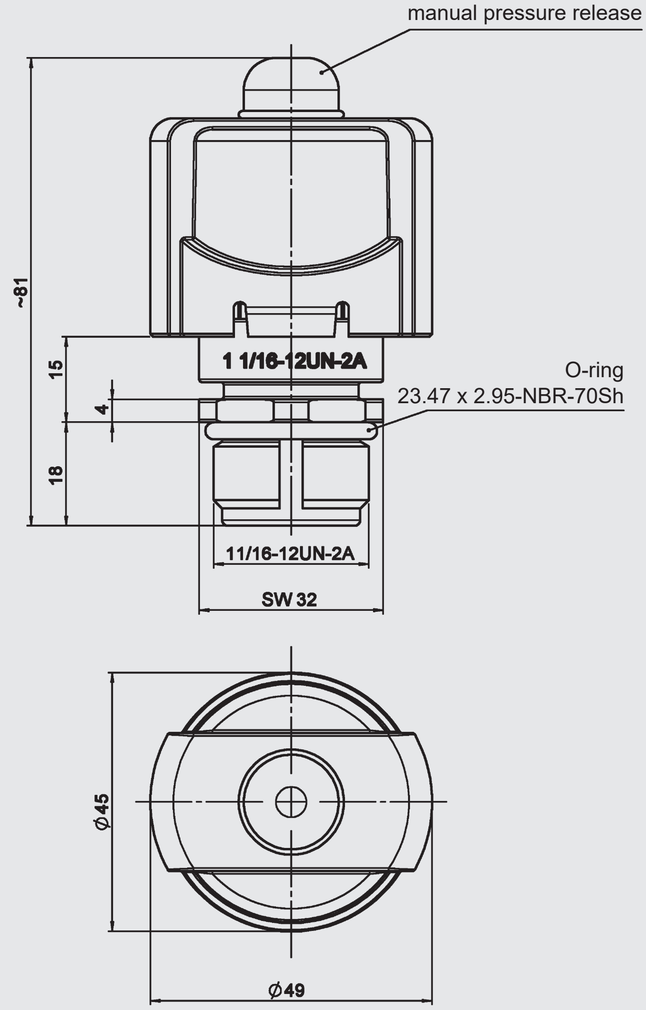
Max. flow rate: 200 l/min
Weight: 0.22 kg

Curves and further information on request.

MODEL CODE

Type	Filter material	Size	Type of connection	Filtration rating [µm]	Type of clogging indicator	Type code	Modification number	Supplementary details
BFPR	**P** = phenolic resin impregnated paper	**10**	**U** = 1 1/16-12UN-2A others on request	**3**	**W** = without port (no clogging indicator)	**1**	**.x** = The latest version is always supplied	**RV0.35** = pre-charge pressure 0.35 bar **RV0.7** = pre-charge pressure 0.7 bar **RV1.15** = pre-charge pressure 1.15 bar Required information!

DIMENSIONS



TECHNICAL DESCRIPTION

The latest breather filter development from HYDAC is the BF 6.

The BF 6 can be fitted with a hydrophobic filter element ("DRY") with an ~ 1,500 cm² filter surface, thus removing any water spray.

Option available with four integrated check valves to enable tank pre-charging – even at different pressure settings.

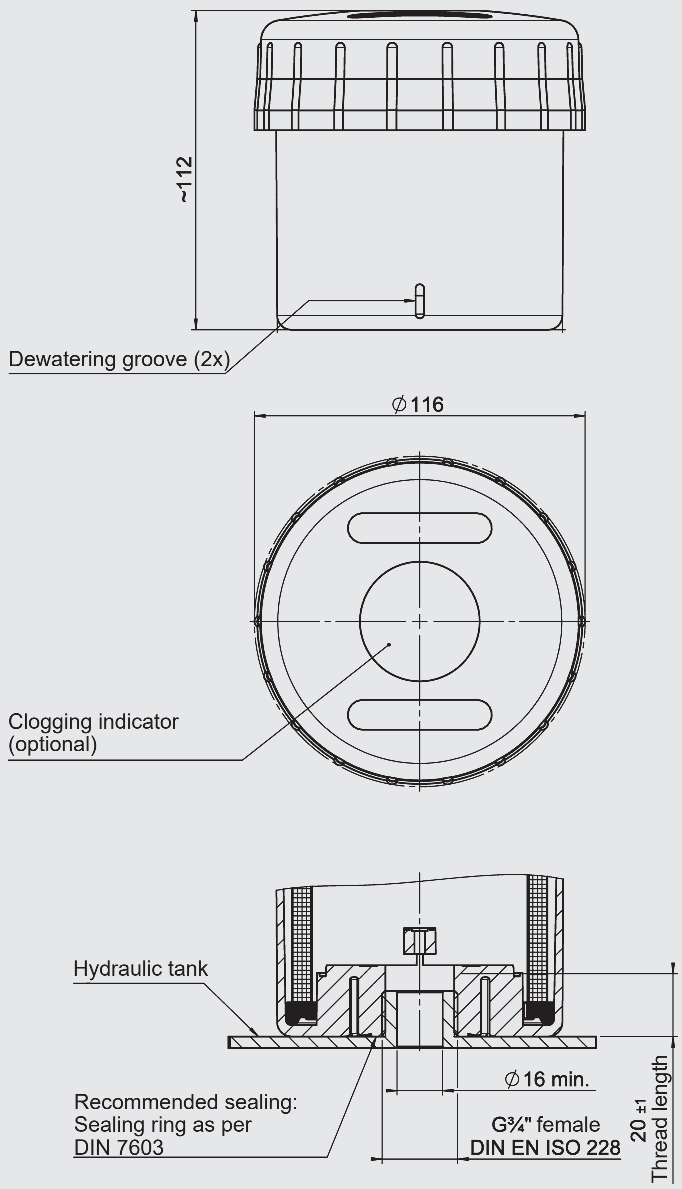
- Max. flow rate: 500 l/min
- Material: plastic (PA 6)
- Sealing material: NBR; HNBR
- Filter material: hydrophobic material (DRY) or material impregnated with phenol resin (P)
- Connections: G ¾ (inner)
- Weight: 0.3 kg

Please contact us for further information and characteristics!

MODEL CODE

Type	Filter material	Size	Type of connection	Filtration rating [µm]	Type of clogging indicator	Type code	Modification number	Supplementary details
BF	**DRY** = Hydrophobic material **P** = Material impregnated with phenol resin	**6**	**G** = Thread G 3/4 More available on request	**5**	**W** = No clogging indicator option **K** = Pressure gauge (pressure setting -1 to +0.6 bar)	**1**	**.x** = The latest version is always supplied	**RV0.3** = Pre-charge pressure 0.3 bar

DIMENSIONS



3. FILTER CALCULATION / SIZING

3.1 SINGLE PASS FILTRATION PERFORMANCE DATA FOR AIR FILTER ELEMENTS

The following separation values were established under real-life simulated conditions.
This means that the selected velocity of the flow against the filter mesh-pack was 20 cm/s and the contamination added was 40 mg/m³ of ISO MTD test dust.

Filtration rating	Retention value d...	For particle size	Filter material
3 µm	d 80	0.74 µm	Paper
	d 100	2.64 µm	
10 µm	d 80	0.25 µm	BN
	d 100	0.84 µm	

The d 80 value refers to the particle size which is filtered out at a rate of 80% during the retention test. The particle size determined by this method is called the nominal filtration rating of the air filter. The d 100 value therefore refers to the particle size which is filtered out at a rate of 100% during the single pass test. The particle size determined by this method is called the absolute filtration rating of the air filter.

Table of average dust concentrations in real life:

Urban regions with a low level of industry	3–7 mg/m³ air
General mechanical engineering	9–23 mg/m³ air
Construction industry (wheeled vehicles)	8-35 mg/m³ air
Construction industry (tracked vehicles)	35-100 mg/m³ air
Heavy industry	50-70 mg/m³ air

3.2 DIFFERENTIAL PRESSURE ACROSS BREATHER FILTER

The differential pressure (with clean element) for the various filter sizes is shown in the graphs under Point 3.4.

3.3 SIZING GUIDELINES

The rate at which contamination enters a hydraulic system can be considerably reduced by using efficient tank breather filtration.

Caution:

Incorrectly sized tank breather filters can place additional strain on the system and reduce the service life of hydraulic filter elements.

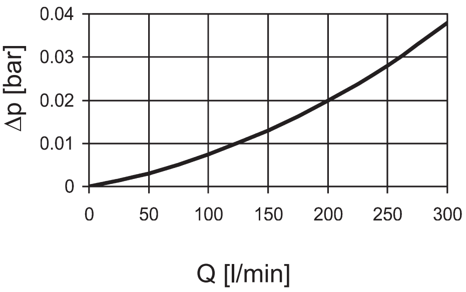
For optimum sizing the following should therefore be observed:

- Filtration rating of breather filter ≤ filtration rating of hydraulic filter
- Only use breather filters with an absolute retention rate (d100 ≤ x µm; x = given filtration rating)
- Max. permitted initial pressure loss: 0.05 bar, optionally 0.01 bar (with a clean filter element and calculated air flow rate)
- Determining the calculated air flow:
  Q_A = f5 x Q_p
  Q_A = calculated air flow in l_N/min
  f5 = factor for operating conditions
  Qp = max. flow rate of the hydraulic pump in l/min

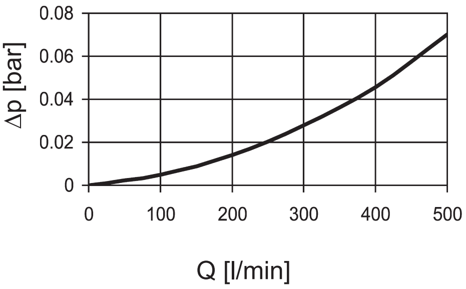
Ambient conditions	Factor f5
Low dust concentration; filter fitted with clogging indicator; continuous monitoring of the filter	1–2
Average dust concentration; filter without clogging indicator; intermittent monitoring of the filter	3–6
High dust concentration; filter without clogging indicator; infrequent or no monitoring of the filter	7–10

3.4 AIR FLOW RATE

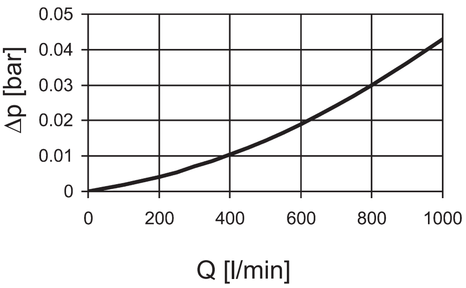
BF 4



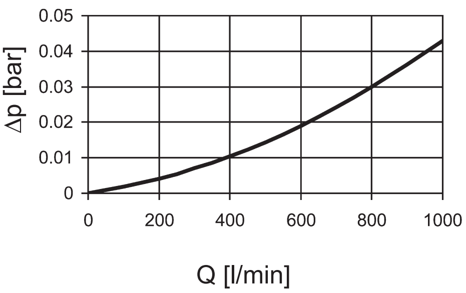
BF 10



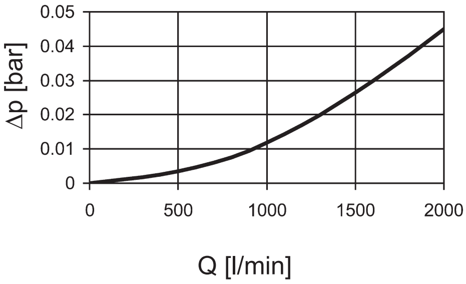
BF 3



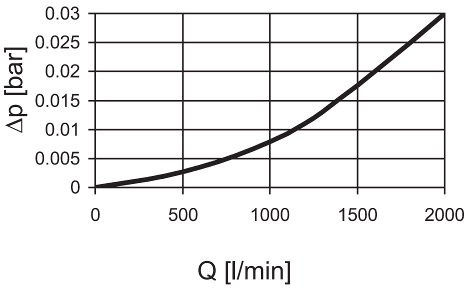
BF 30



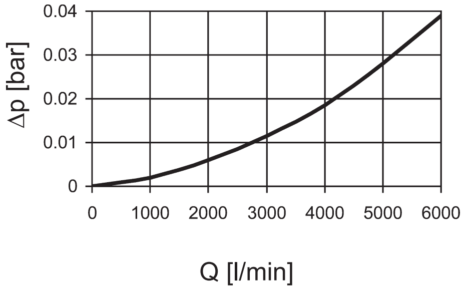
BF 7



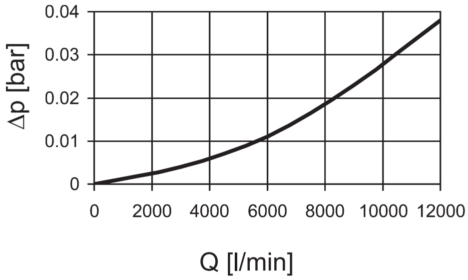
BF 72



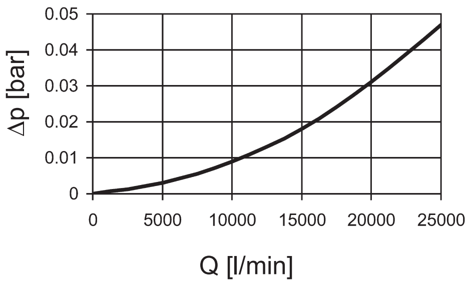
BF 5



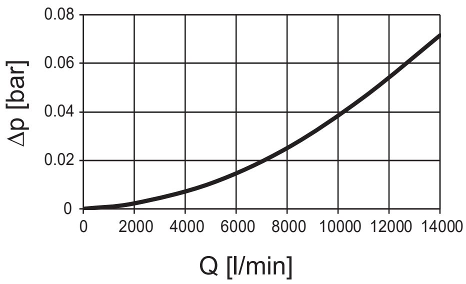
BF 52



BF 8



BF 9



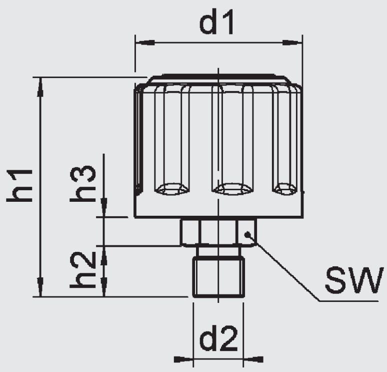
Pressure drop curves for BF filters with check/bypass valve (version /-RV...) on request.

4. DIMENSIONS

Tank requirements

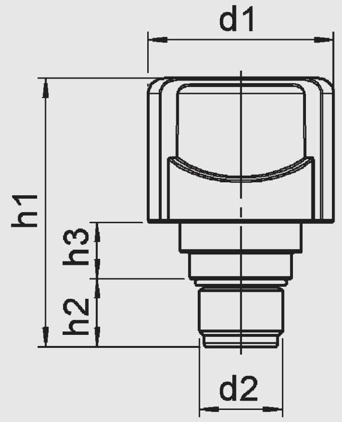
1. In the filter contact area, the tank flange should have a maximum flatness of 0.2 mm and Ra 3.2 µm maximum roughness.
2. In addition, the contact area should be free of damage and scratches.
3. Both the tank sheet metal and/or the filter mounting flange must be sufficiently robust so that neither deform when the seal is compressed during tightening.

BF 4



Type	BF 4...
d1	44
d2	G ¼
h1	58
h2	14
h3	8
SW	17
Weight	~ 0.08 kg

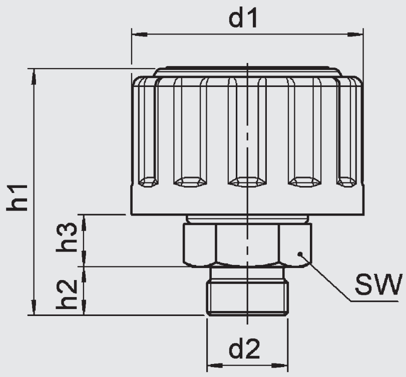
BF 10



Type	BF 10 "G"...	BF 10 "M"...
d1	49	49
d2	G ¼	M22x1.5
h1	63	71
h2	14	18
h3	11	15
Weight	~ 0.05 kg	~ 0.05 kg

Type	BF 10 "U"...	BF 10 "N"...
d1	49	49
d2	1 1/16-12 UN	NPT ½
h1	71	71
h2	18	18
h3	15	15
Weight	~ 0.05 kg	~ 0.05 kg

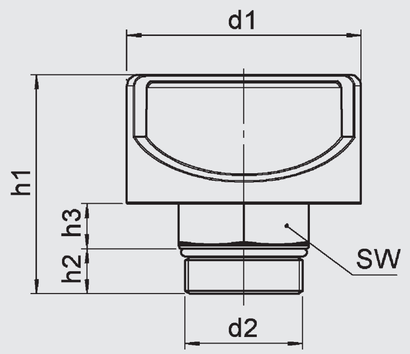
BF 3



Type	BF 3...1.X
d1	76
d2	G ¾
h1	81
h2	16
h3	17
SW	36
Weight	~ 0.35 kg

Type	BF 3...2.X	BF 3...3.X
d1	76	76
d2	G 3/8	G ½
h1	76	78
h2	12	14
h3	16	16
SW	22	27
Weight	~ 0.35 kg	~ 0.35 kg

BF 30

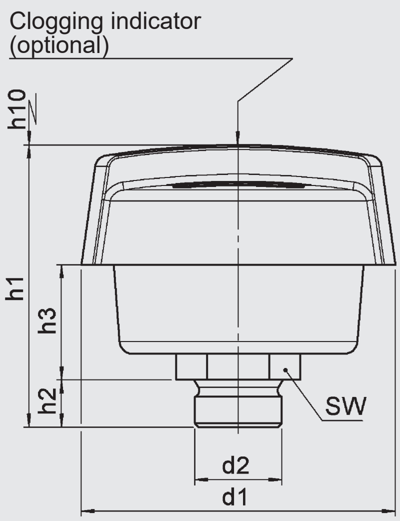


Type	BF 30 "G"...1.X
d1	83
d2	G ¾
h1	76
h2	16
h3	14
SW	32
Weight	~ 0.15 kg

Type	BF 30 "M"...1.X	BF 30 "M"...2.X
d1	83	83
d2	M42x2	M30x1.5
h1	76	76
h2	16	16
h3	16	14
SW	46	32
Weight	~ 0.15 kg	~ 0.15 kg

Type	BF 30 "U"...1.X	BF 30 "N"...1.X
d1	83	83
d2	1 1/16-12 UN	NPT ¾
h1	76	76
h2	16	16
h3	14	14
SW	32	32
Weight	~ 0.15 kg	~ 0.15 kg

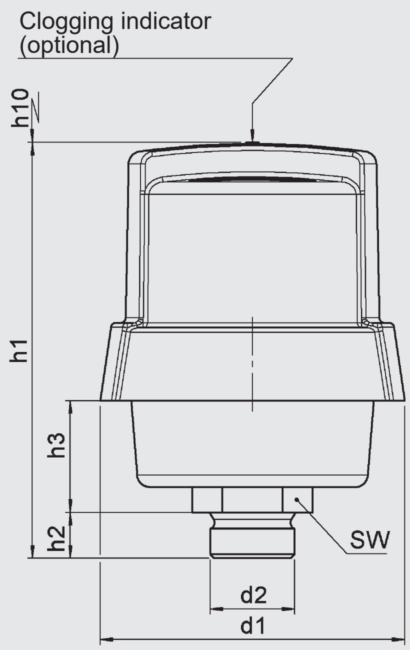
BF 7



Type	BF 7 "G"	BF 7 "M"
d1	120	120
d2	G 1	M30 x 1.5
h1	108	108
h2	18	18
h3	44	44
h10	60	60
SW	41	36
Weight	~ 0.30 kg	~ 0.30 kg

Type	BF 7 "U"	BF 7 "N"
d1	120	120
d2	1 5/16-12 UN	NPT ¾
h1	106	108
h2	18	18
h3	44	44
h10	60	60
SW	41	32
Weight	~ 0.30 kg	~ 0.30 kg

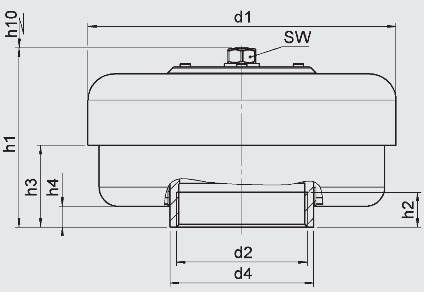
BF 72



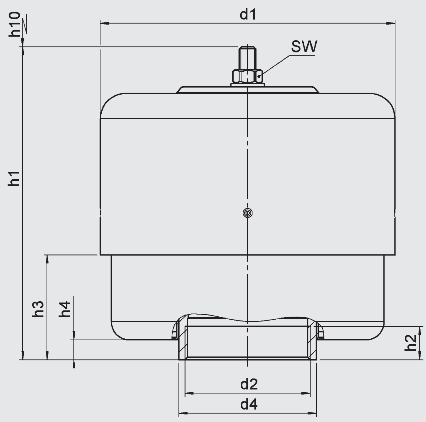
Type	BF 72 "G"	BF 72 "M"
d1	120	120
d2	G 1	M30 x 1.5
h1	164	164
h2	18	23.5
h3	44	44
h10	90	90
SW	41	36
Weight	~ 0.40 kg	~ 0.40 kg

Type	BF 72 "U"	BF 72 "N"
d1	120	120
d2	1 5/16-12 UN	NPT ¾
h1	164	164
h2	18	18
h3	44	44
h10	90	90
SW	41	32
Weight	~ 0.40 kg	~ 0.40 kg

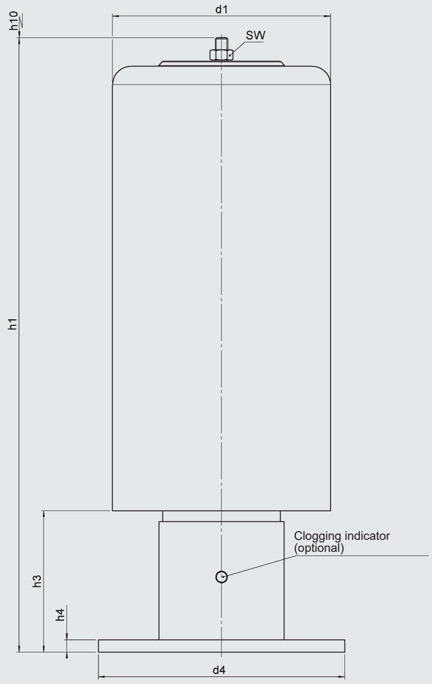
BF 5 / BF 5...RV



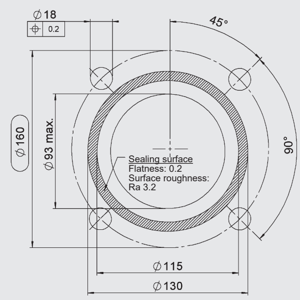
BF 52 / BF 52...RV



BF 8



Flange connection BF 8



Hole pattern and sealing surface, O-ring

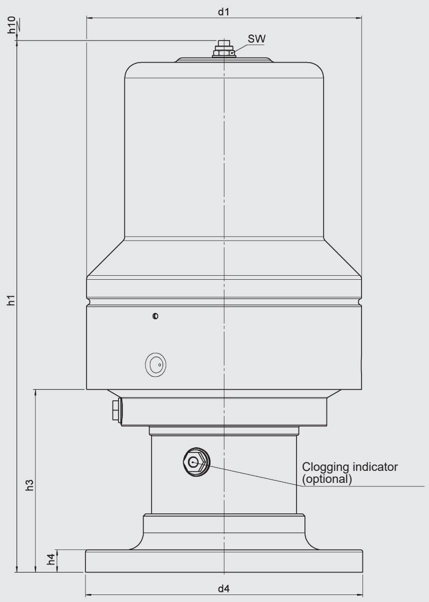
Type	BF 5 "G"...	BF 5 "G".../-RV
d1	177	177
d2	G 2½	G 2½
d4	Ø82.5	Ø89
h1	103	121
h2	$20^{+3/-5}$	max. 18
h3	47	65
h4	12	30
h10	90	90
Weight	~ 1.60 kg	~ 2.75 kg

Type	BF 5 "N"...
d1	177
d2	NPT 2½
d4	Ø82.5
h1	103
h2	–
h3	47
h4	12
h10	90
Weight	~ 1.60 kg

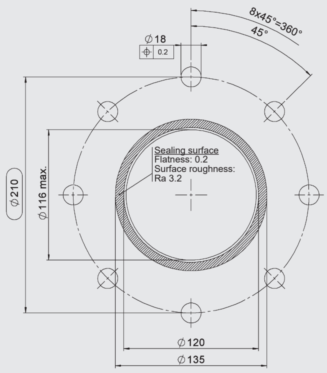
Type	BF 52 "G"...	BF 52 "G".../-RV
d1	177	177
d2	G 2½	G 2½
d4	Ø82.5	Ø89
h1	188	193
h2	$20^{+3/-5}$	max. 18
h3	63	81
h4	12	30
h10	150	150
Weight	~ 2.00 kg	~ 3.00 kg

Type	BF 8...
d1	200
d4	200
h1	497
h3	114
h4	10
h10	400
Weight	~ 10.00 kg

BF 9



Flange connection BF 9



Hole pattern and sealing surface, O-ring

Type	BF 9...
d1	245
d4	247
h1	473
h3	163
h4	20
h10	330
Weight	~ 5.00 kg

NOTE

The information in this brochure relates to the operating conditions and applications described.
For applications or operating conditions not described, please contact the relevant technical department.
Subject to technical modifications.

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