Installation Guide

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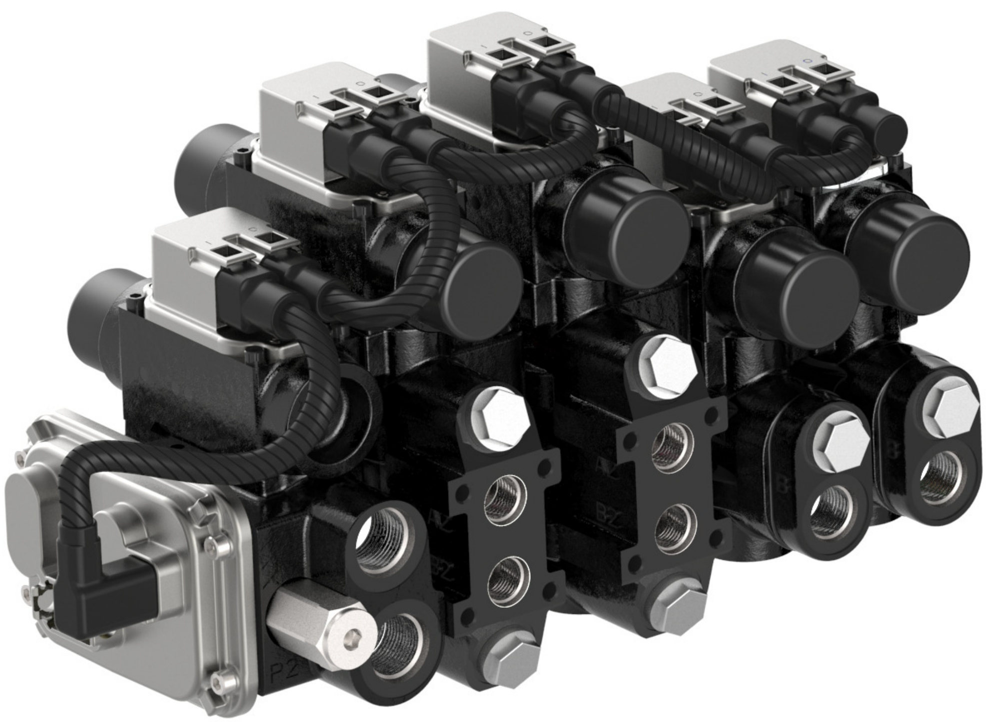
TOMORROW

Boom Stability Control (BSC)



Contents

1 Revision History

Table 1

Revision	Description	By	Date
1.0	Initial version of BSC user manual.	XXX	XXX

2 Background

Boom Stability Control System (BSC) is an active damping technology, part of the CMA software, which significantly reduces shock, persistent, and roading disturbances. Utilizing the integrated pressure sensors, an onboard damping algorithm, and precise valve position control, the CMA valve can quickly detect a disturbance or oscillation and automatically stabilize the boom structure.

3 Document Purpose

The document is intended to be a reference guide for the application and tuning of BSC. This document includes descriptions and instructions for system-level as well as software-specific configuration parameters of BSC.

4 System-Level Architecture

BSC is platform flexible, boom damping solution. The system is suitable for single or multi-boom machines, though typically not required on all boom sections. The required supporting componentry varies depending the platform requirements. Table 2 lists the required and platform-dependent components used in a BSC machine application.

Table 2

Required Components	Platform-Dependent Components
• CMA Valve • Supervisory controller • Operator input device	• High ratio counterbalance valves (CBVs) or Pilot-to-shift valves • Cylinder pressure sensors

The following subsections details the specific features and requirements around components required for the BSC system and may vary dependent on platform.

4.1 CMA Valve

The CMA valve is the core component for BSC. CMA is a CAN-controlled, electro-hydraulic, sectional valve with independent metering. The CMA's unique architecture, on-board electronics and internal pressure/position sensors enable advanced software controls and features. This valve offers industry-leading performance and software programmable flexibility to tune and meet the desired characteristics of the machine application.

4.2 Supervisory Controller

While the BSC algorithm resides entirely within the CMA valve software, a supervisory controller is still required to translate operator inputs, including BSC status, and communicate commands out to the CMA. The supervisory controller communicates to the CMA valve via CANBUS (J1939 or CANOpen).

4.3 Operator Input Device

In conjunction with the supervisory controller, an operator input device is required to control the machine and to enable/disable BSC. The choice of input is flexible and can be a machine-based joystick/switch for example or a remote-control arrangement. The input device will be read by the supervisory controller and translated into the necessary commands sent to the CMA.

4.4 Counterbalance / Pilot-to-Shift Valves

For applications requiring load holding valves, high-ratio counterbalance or pilot-to-shift valves are required for BSC to provide optimal performance. Pilot ratios greater than 6:1 or a pilot-to-shift pressure of ~50 bar is recommended. Additionally, the load holding valves must be externally drained or atmospherically vented for BSC to function properly.

Danfoss offers an assortment of counterbalance/over-center valves for any machine size or application. The 1CEBDH30, 1CPBD30/90/120 over-center valves are suitable for BSC applications.

Note: When selecting a valve, ensure size is appropriate for the desired flow and port relief valves are added if not already integrated into the valve.

4.5 Cylinder Pressure Sensors

External pressure sensors located at the cylinder ports are recommended for applications with load holding valves or hose lengths exceeding 10m (32ft) on a BSC-enabled work function. In these scenarios, the CMA's internal pressure sensors may not provide an accurate measurement of the cylinder pressure required for BSC to function properly.

The external pressure sensor recommended resolution is ≤ 0.1 bar and the required update rate depends on the natural frequency of the system. For example, a boom that oscillated around 1 Hz: the time from pressure event to signal received at CMA had to be <70 ms. An update rate of 20 Hz is recommended as a starting point and can be adjusted for the specific application.

To minimize noise, the recommended sensor output is 4-20mA or a CAN based sensor. The measurements from the sensors must be processed in real-time by a secondary controller and the sensor values communicated to the CMA via compatible CAN messaging. See Section 5.5 below for additional details.

5 BSC Standard Tuning Parameters

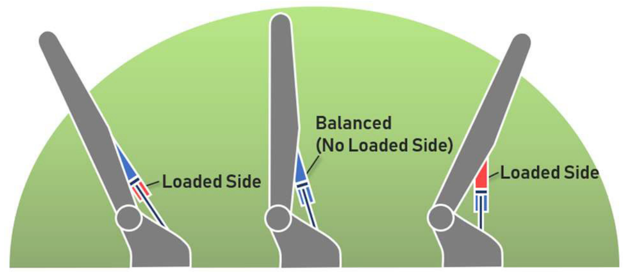
BSC is intended for a wide variety of machine applications and is robust to different boom lengths, loads, and natural frequencies. As a result, it must be tuned to each machine platform via several parameters within the CMA Object Dictionary (OD). Table 5 in Appendix A lists all tunable parameters relevant to BSC function and performance. The following subsections describe the standard parameters in more detail and basic tuning recommendations.

Note: It is recommended that these parameters be configured using Po-FX configure.

5.1 BSC Loaded Side

To function properly, the BSC algorithm must know which side of the boom's cylinder is loaded during operation, see Figure 1 below.

Figure 1



The loaded side can be determined one of two ways:

1. Automatically detected via the CMA software algorithm.
2. Manually set via the BSC Loaded Side parameter for booms which do not go over center.

The BSC Loaded Side parameter can be set to three options: work port A loaded, work port B loaded, or automatic load side detection, shown in Table 3 below. If it is only possible for one side to be loaded in the application, it is recommended to specify the BSC Loaded Side.

Table 3

Condition	BSC Loaded Side Setting
Work port A always loaded	1
Work port B always loaded	2
Either side could be loaded	-1

Caution - Selecting the loaded side of the cylinder incorrectly may cause the boom to fall.

Note: Work-port B corresponds to the port under the daisy-chain cabling.

5.2 BSC External Sensor Configuration

The BSC algorithm requires cylinder pressure sensing in order to function. The CMA can be configured to leverage internal or external sensors depending on the application and system configuration. The BSC External Sensor Configuration parameter defines which sensors the CMA will use as inputs, see Table 4 below.

Table 4

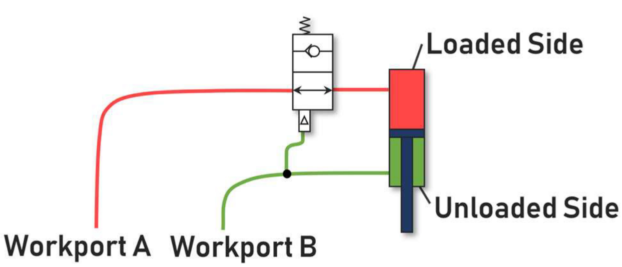
Parameter Value	Pressure Sensor Configuration
1	Work port A External / Work port B Internal
2	Work port A Internal / Work port B External
3	Work port A & B External
4	Work port A & B Internal

The external pressure sensor data is communicated to CMA leveraging the WriteRequest message (Message Index 18, OD Index 513 or 0x4201 in CANOpen), defined in the CMA Application Developers Guide. The sensor data must be converted to centibar and packed into 32 bits; with port A sensor packed into bits 0-15 and port B sensor into bits 16-31.

5.3 Unloaded Side Pressure Demand

The Unloaded Side Pressure Demand defines the port pressure for the non-load holding side of the function, see Figure 2 below,

Figure 2



The Unloaded Side Pressure Demand parameter is important for applications using counterbalance or pilot-to-shift valves. The value of this parameter should be set to a pressure high enough to fully open the loaded-side counterbalance valve, e.g. CMA value: 3500 (cbar) = 35(bar)*100.

Note: To achieve the best pressure control performance, tuning may be required of the work port hose volume parameter.

5.4 Boom Stability Damping Gain

The Boom Stability Damping Gain is the primary configuration parameter governing the strength of BSC's oscillation damping. A higher value for this gain will lead to more damping flow, however, raising this gain too high can amplify noise and make starting and stopping boom movement less responsive.

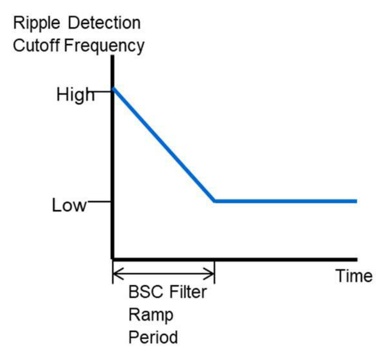
The value of this parameter varies depending on the application cylinder sizing and the amplitude of the pressure oscillations within the cylinder. For smaller applications such as a fire truck ladder (ex. Bore 170mm/Rod 120mm), a recommended starting value for this gain is 150. For larger applications such as a concrete pump (ex. Bore 400mm/Rod 180mm), a recommended starting value is 1500.

5.5 Ripple Detection Cutoff Frequency (High/Low)

The Ripple Detection Cutoff Frequency High/Low are the parameters to define the damping frequency range. It is a high-pass filter on service pressures to determine the boom oscillation ripple to dampen out.

To smooth start/stop transitions, the frequency is ramped in from a high value to a low value and this allows the filter to "learn" the load pressure to maintain, see Figure 3 below.

Figure 3



The Ripple Detection Cutoff Frequency High/Low, and the BSC Filter Ramp Period are configurable within CMA. It can be challenging to know the frequency of the load; therefore, it is recommended to set the low filter frequency slightly below the oscillation frequency. Setting the Ripple Detection Cutoff Frequency Low is a tradeoff. Setting it lower will increase the BSC damping effect, but setting it too low will make the system more sluggish to respond to actual changes in the load pressure.

For the low frequency cutoff, a default value of 0.2 Hz, e.g. CMA value: 410 = 0.2*2048, typically works well for a load oscillating at >0.4 Hz. The high frequency cutoff default value is 3.9 Hz, e.g. CMA value: 8000 = 3.9*2048, and the filter ramp period default value is 3.9 Hz, e.g. CMA value: 700 or 300 * 1.5 ms (sample time) = 1.05s. The specific application and boom characteristics may require additional tuning to achieve desired performance.

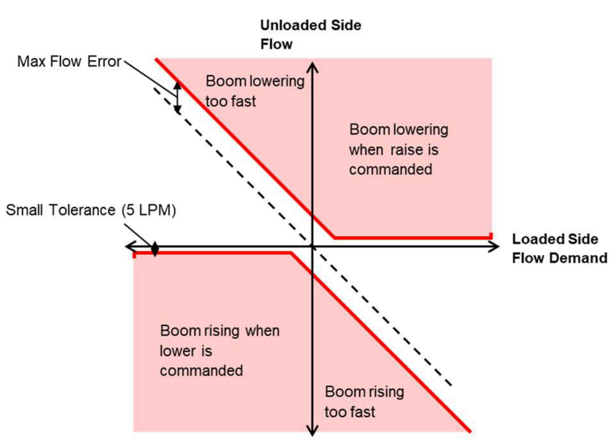
Note: Setting the filter frequency too low can cause unintended movement if the load pressure changes quickly. Examples: cylinders going vertical, loads being added/removed, starting/stopping, or other services inducing loads. It is recommended to evaluate the parameter setting across all working conditions.

5.6 Max Flow Error on Unloaded Side and BSC Error Timeout

In conjunction with load holding valves, BSC has an integrated fault to prevent a load from dropping in the event of a hose burst. If a rupture occurs, the algorithm limits flow on the unloaded side of the cylinder and calculates the error between the demanded meter-in flow and the actual work port flow. If the error is greater than a specified threshold for a certain period, the CMA will enter a fault state and the valve is idled. This ensures the cylinder's unloaded side port pressure is suitably low to seat the load holding valves and stop function movement.

This fault will only occur if the boom is moving faster than commanded in either direction or if the boom is moving in the opposite direction of the command. SeeError! Reference source not found. 4 for a graphical representation fault region.

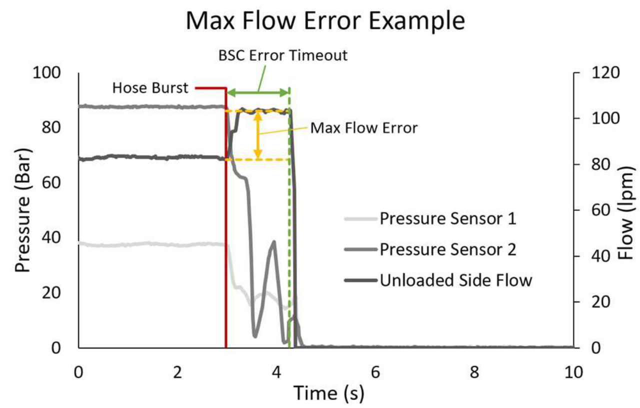
Figure 4



Note: While the Max Flow Error shown in the above figure is configurable via the Max Flow Error on Unloaded Side parameter, the Small Tolerance is always a constant 5 LPM.

An application example of the max flow error fault is shown in Figure 5 below.

Figure 5



The parameters to define the flow error threshold and error timeout duration are <u>Max Flow Error</u> and <u>BSC Error Timeout</u> respectively. The <u>Max Flow Error</u> default is set to 20 lpm, e.g. CMA value: 20 lpm * 32 = 640. The <u>BSC Error Timeout</u> default value is 450 ms, e.g. CMA value: 300 or 300 * 1.5 ms (sample time) = 450ms. To achieve the best performance, additional tuning may be required depending on the application or system configuration.

<u>Caution</u> - BSC does not prevent or protect against hose burst or the potential for the load or boom to drop in the case of such a failure. Load holding valves must be installed for applications requiring load holding or hose burst protection.

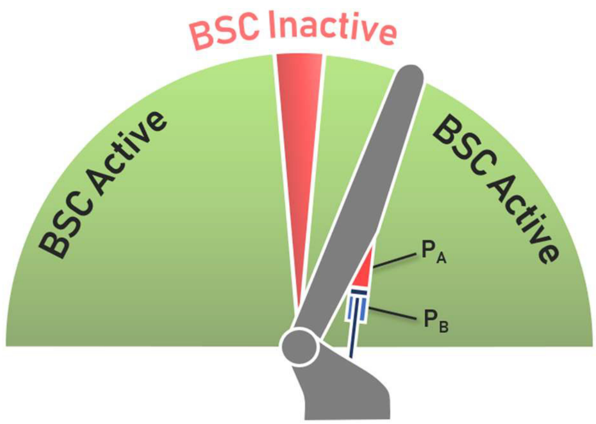
6 BSC Advanced Parameter Tuning

For certain machine applications, the use of additional tuning parameters may be required to achieve optimal performance. Table 5 in Appendix A lists all tunable parameters relevant to BSC function and performance. The following subsections describe the advanced parameters in more detail and basic tuning recommendations.

6.1 BSC Minimum Pressure Differential and BSC Exit Hysteresis

For over-center boom applications, BSC is disabled in the over-center transition region of motion as the damping effectiveness is limited when the boom is positioned vertically. See Figure 6for an example of the BSC active/inactive regions.

Figure 6



BSC is active when it detects a minimum pressure differential between the loaded and unloaded side of the cylinder. The BSC Minimum Pressure Differential parameter defines this pressure differential based on the cylinder area corrected pressures in the rod and cap end. The following equation defined whether BSC is active:

$$\left|P_A - P_B\frac{A_A}{A_B}\right| > BSC\ Minimum\ Pressure\ Differential$$

The BSC Minimum Pressure Differential is typically set to 45 bar, e.g. CMA value: 4500 (cbar) = 45*100.

The BSC Exit Pressure Hysteresis is subtracted from the BSC Minimum Pressure Differential to allows BSC to remain active for slightly longer before transitioning into the inactive state. This prevents undesired bouncing between BSC active and inactive states. Hence BSC is inactive when the following condition is detected:

$$\left|P_A - P_B\frac{A_A}{A_B}\right| < (BSC\ Minimum\ Pressure\ Differential - Exit\ Pressure\ Hysteresis)$$

The BSC Exit Pressure Hysteresis is typically set to 5 bar, e.g. CMA value: 500 (cbar) = 5*100.

6.2 BSC Force Filter Coefficient

In certain situations, a high frequency noise may be present in the BSC damping flow demand, and to mitigate this issue, the algorithm leverages a low-pass filter on the cylinder force, $(P_1A_1 - P_2A_2)$. The cutoff frequency of this filter is controlled by the BSC Force Filter Coefficient parameter.

The value of this parameter influences the cutoff frequency via the following equation (wheref_c is the cutoff frequency):

$$k_{filter} = e^{-2\pi*0.0015*f_c} * 2^{15}$$

The BSC Force Filter Coefficient should be set to a cutoff frequency slightly above the highest frequency of the structural vibration that is to be damped out. The default is set at k=30000= 9.3 Hz.

6.3 BSC Pressure Sensor Filter Coefficient

The BSC Pressure Sensor Filter Coefficient is another parameter, like the BSC Force Filter, used to remove undesired high-frequency noise. The BSC algorithm leverages a low-pass filter on internal/external pressure sensor measurements used for control.

The value of the BSC Pressure Sensor Filter Coefficient influences the cutoff frequency of the filter via the following equation (where f_c is the cutoff frequency):

$$k_{filter} = e^{-2\pi*0.0015*f_c} * 2^{15}$$

Setting the cutoff frequency of this filter too low can create phase lag in the system and lead to instability. The recommended setting for this frequency is as high as possible before noise shows up on the flow command signal out of the BSC algorithm. The default is set at k=29000 = 13 Hz.

Note that these two filters can add phase lag to the pressure signals, which can result in high-frequency oscillations in some applications. If oscillations are observed, try increasing the frequency of these filters or set them to 0 to disable them.

6.4 BSC Pressure Deadband

In sections 6.2 and 6.3, methods were discussed to reduce the effect of noise on pressure sensor readings. One additional option to combat noise is the BSC Pressure Deadband. Any pressure ripple that falls within the pressure Deadband will be ignored by the BSC algorithm.

A recommended starting value for this parameter is ≤ 100 centibar. If this parameter is too high, the damping performance of BSC will be degraded.

6.5 BSC Heavy Load Pressure Threshold, Pressure Demand, and Flow Threshold

In applications with load holding valves, the BSC algorithm partially pressurizes the unloaded side of the cylinder in order to open the load holding valve. This in turn raises the load pressure, which can reduce the load capacity of the system when nearing maximum supply pressure.

To counter this, BSC has a Heavy Load mode which will lower the unloaded side pressure target to a lower value, the BSC Heavy Load Pressure Demand parameter, if the following two conditions are met:

1. Load pressure > BSC Heavy Load Pressure Threshold
2. Flow demand > BSC Heavy Load Flow Threshold

The BSC Heavy Load Pressure Threshold is typically set to 30-50 bar below the maximum supply pressure, e.g. CMA value: 32000 (cbar) = 320*100.

The BSC Heavy Load Flow Threshold should be set high enough such that adding the BSC damping flow to the base flow demand does not change the direction of flow to the loaded side. The default value is 10 lpm, e.g. CMA value: 320 = 10*32.

6.6 Initialization Pressure Ramp

For applications which require a smoother start when BSC is first activated, there is an optional pressure ramp that can be applied to charge the pressure in the hoses. This is a 2-step ramp: first the loaded side pressure is increased up to the higher of the pressure measured by an external loaded side pressure sensor or the BSC Load Pressure Target. This can be set to an estimate of a typical load pressure; if it is slightly below the actual load pressure, the movement when the CBV opens should be minor.

The hose charging ramps will only be activated if the BSC Pressure Ramp Rate parameter is non-zero. If the ramps are activated, after the loaded side hose reaches the BSC Load Pressure Target, then the unloaded side pressure will be ramped up to the Unloaded Side Pressure Demand at the specified ramp rate. The units of the ramp are in centibar per 1.5 ms.

There is a final parameter which tunes the initial hose charging ramps. There is a rate limit on the flow demand when transitioning from the hose charging state to the BSC active state. Since the user demand is ignored during the charging ramp, the BSC Flow Ramp Limit parameter is provided to prevent a large jump in flow when the ramps are completed. The units of the Flow Ramp Limit are lpm*1024 per 1.5ms.

6.7 Maximum Damping Flow

The BSC Maximum Damping Flow parameter can be used to limit the amount of damping flow that can be applied by the BSC algorithm. By default, this parameter is set to be large to avoid limiting BSC. Lowering this parameter will decrease the effectiveness of BSC, but it will ensure that the flow demand to the spool remains closer to the user demand.

7 Drift Compensation

While BSC is active the boom can move slightly in order to provide the best damping performance. For applications which have a continuous or cyclical disturbance, this slight movement can manifest as drift over time if no corrective measures are taken. For these applications it is recommended to include an external means of drift compensation in order to keep the boom on the desired location.

Note: Drift compensation is not part of the BSC or CMA internal algorithms. Implementation must be done on the supervisory controller commanding CMA.

7.1 Hardware Considerations

Measurement of the boom position can be achieved via several types of sensors, e.g. cylinder position, inclinometer, etc. To minimize noise, the recommended sensor output is 4-20mA or a CAN based sensor.

7.2 Algorithm Considerations

A standard proportional feedback controller will work for most applications. The drift compensation algorithm should only be active while the boom is static and disabled if the boom section is being moved.

Caution – Note: If using absolute inclination sensors, moving one service can affect the angle of a non-moving service, causing it to look like drift. In this case, it is recommended to disable drift prevention whenever ANY service is moving.

8 Terminology

CAN = Controller Area Network. CAN is a digital communication message based protocol. It provides a simple method for microcontrollers to communicate with each other on the same physical layer. Each device (commonly referred to as a node) can serially transmit and receive messages. Bit rates (baud rates) can be as high as 1 Megabit per second on network that are less than 40 meters in length.

CBV = Counterbalance valve.

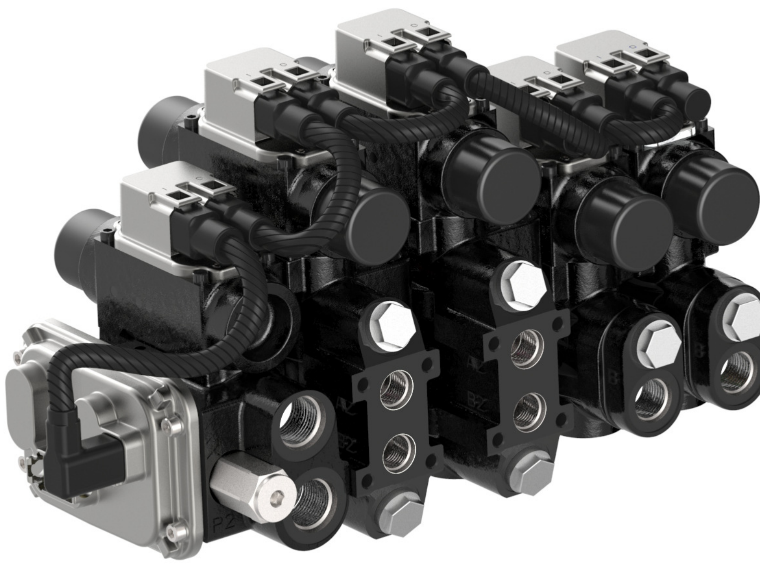
CMA = Advanced CAN-controlled electrohydraulic sectional mobile valve product offered by Danfoss.

IFC = Intelligent Flow Controller. This is a control mode within the CMA valve where the valve will meter the loaded side (flow control) while maintaining a constant pressure on the unloaded side (pressure control).

LPM = Liters per Minute. This is a unit of fluid flow rate.

OD = Object dictionary. This is a table which has the same structure for all types of devices. With this it is possible to access all important data and parameters of a device using a king of logical addressing system (index, subindex) from the “outside,” i.e. via the CAN bus. Access to the OD is provided by means of the V2SI protocol.

WP = Workport.



9 Appendix A

Table 5

Parameter Name	Parameter Description	Default Value	Units	OD Index in OD 5.3 J1939 [CANOpen]
Boom Stability Damping Gain	Boom Stability Damping Gain	0		939 [0x43AB]
Unloaded Side Pressure Demand	Pressure demand for the unloaded side in BSC	0	cbar	941 [0x43AD]
Ripple Detection Cutoff Frequency (Low)	Final high pass filter cutoff frequency	410	Hz*2048	914 [0x4392]
Ripple Detection Cutoff Frequency (High)	Initial high pass filter cutoff frequency	8000	Hz*2048	915 [0x4393]
BSC Select Loaded Side	Select loaded side (2 = WP2 is loaded 1 = WP1 is loaded -1 = AutoDetect)	-1		942 [0x43AE]
BSC External Sensor Configuration	Configure external sensors. 1=P1 External 2 =P2 External 3 =Both External Else=Both Internal	4		944 [0x43B0]
Max Flow Error on Unloaded Side	Meter-In flow error threshold for detecting an overflow fault	640	lpm*32	603 [0x425B]
BSC Error Timeout	Timeout for detecting a flow error or low pressure fault	333	counts	916 [0x4394]
BSC Heavy Load Pressure Threshold	Load pressure threshold for detecting a heavy load where the back pressure needs to be lowered	26000	cbar	952 [0x43B8]
BSC Heavy Load Pressure Demand	Unloaded side pressure demand in heavy load conditions	1000	cbar	917 [0x4395]
BSC Heavy Load Flow Threshold	Flow demand threshold for enabling the heavy load condition.	320	lpm*32	953 [0x43B9]
BSC Minimum Pressure Differential	Minimum area-modified pressure difference needed to enable BSC. Typically needed when auto-detecting the load side	4500	cbar	954 [0x43BA]
BSC Exit Pressure Hysteresis	Hysteresis on area-modified pressure used to determine when to exit BSC	500	cbar	963 [0x43C3]
BSC Filter Ramp Period	Period for load force filter to ramp from its initial (fast) frequency to its final (slow) frequency	700	counts	918 [0x4396]
BSC Force Filter Coefficient	Low-pass filter on the load force	30000		605 [0x425D]
BSC Initialization Exit Pressure	Pressure needed to exit the initialization state	0	cbar	964 [0x43C4]
BSC Pressure Sensor Filter Coefficient	Second order low-pass filter on the pressure sensors	29000		606 [0x425E]
BSC Pressure Deadband	Deadband on the detected pressure ripple to be excluded from damping	0	cbar	607 [0x425F]
BSC Load Pressure Target	Target pressure for charging the loaded side hose before starting	0	cbar	630 [0x4276]
BSC Pressure Ramp Rate	Ramp rate for charging the unloaded side hose before starting	0	Cbar/1.5ms	919 [0x4397]
BSC Flow Ramp Limit	Rate limit on flow demand when exiting the initialization ramps	0	Lpm*1024/1.5ms	949 [0x43B5]
BSC Max Damping Flow	Max flow modification that can be applied by BSC	6400	Lpm*32	947 [0x43B3]

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