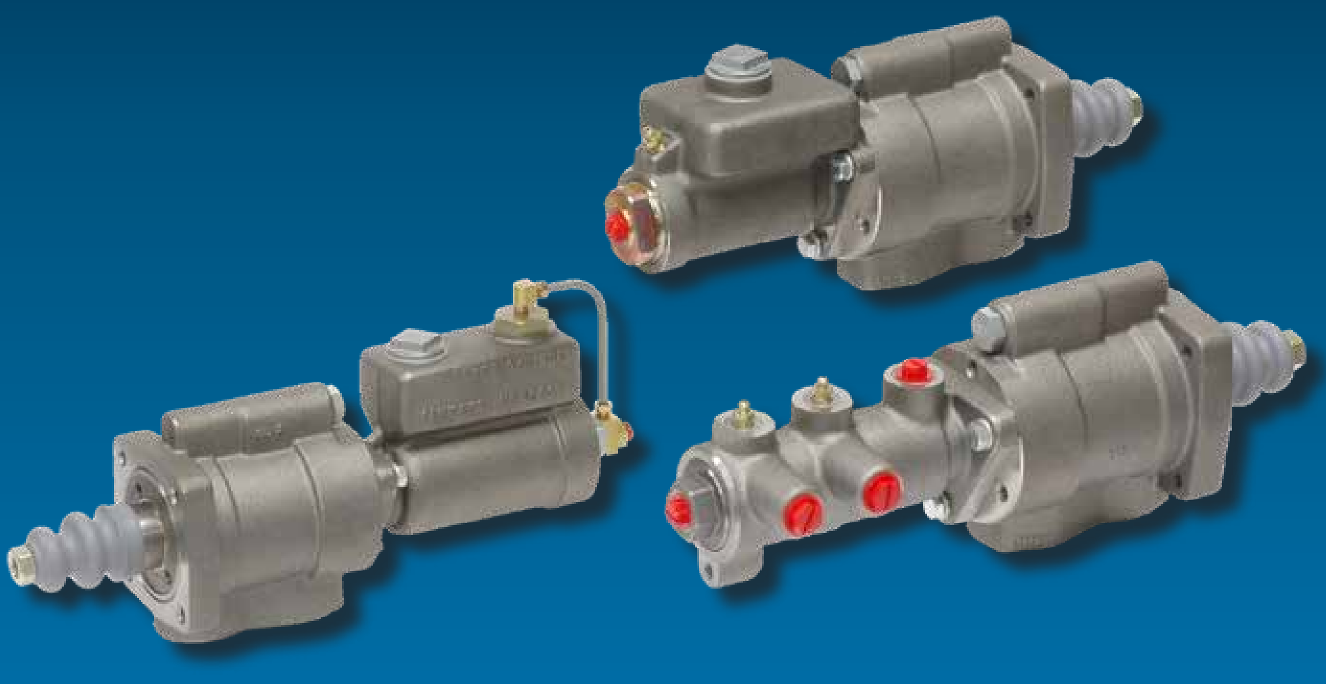
BOOSTED MASTER CYLINDERS

Hydraulically boosted straight bore master cylinders, tandem master cylinders, and two-stage master cylinders



ZF Off-Highway Solutions Minnesota Inc. designs, manufactures, and markets hydraulic components, controls, and brake systems, primarily for off-highway markets.

Many of the world's largest Off-Highway OEMs value the knowledgeable staff at ZF Off-Highway Solutions Minnesota Inc. and work with us to make their products better. Our custom-engineered products are designed with the customer requirements as the primary driver. It is our intent to help customers build their systems with our expertise in hydraulic components, braking systems, and controls. Our goal is to meet or exceed our customers' expectations in every aspect of our business.

ZF Off-Highway Solutions Minnesota Inc. continuously strives for improvement, while remaining a quality leader in our field. We are a successful, customer driven business. We look forward to working with you!

Boosted Master Cylinders

The same dependability and performance that goes into every ZF Off-Highway Braking Solutions Minnesota Inc. product also goes into our versatile, high-performance Boosted Master Cylinders. This is an important consideration when you select a source of supply for your fluid power needs.

The ZF Boosted Master Cylinders presented in this catalog are designed for use in machines that are equipped with other hydraulic power devices. This design feature eliminates the need for a separate system to provide power for the boosted master cylinder.

The Boosted Master Cylinders combine a booster section (see page 4 and 5) with a master cylinder section (see pages 6 through 9) in a single unit. The booster section utilizes power from a vehicles existing open center or load sensing hydraulic system to boost the master cylinder section. The booster section will typically use mineral base hydraulic oil, while the master cylinder will use DOT brake fluid.

The Boosted Master Cylinders provides the machine operator a pedal feel directly proportional to the brake pressure, and therefore, provides excellent modulation.

The master cylinder section of the actuator remains manually functional in the event of main power system loss, or "power-off." A power-off brake apply does require greater pedal force and pedal travel than during power-on apply.

This catalog is designed to assist you in making an initial selection of a boosted master cylinder suited to your requirements. Complete the appropriate Application Data Sheet online, www.mico.com, and submit to sh-applications.NMN@ZF.com. The ZF Off-highway Solutions Minnesota Inc. Applications Department will analyze your specifications and based on your input recommend a boosted master cylinder suitable for your requirements.

Edition 1

Version 1 (04.2023)

84-460-007 (en)

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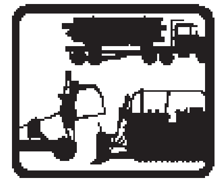
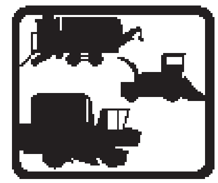


Forestry Equipment



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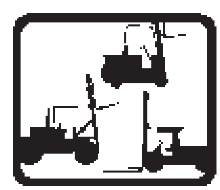

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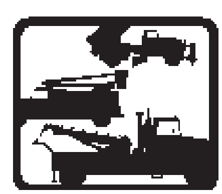


Service & Utility Vehicles

Operation of Boosted Master Cylinders

Non-Actuated Position

(Refer to Figure 1)

The master cylinder section is not actuated and remains in the static condition without mechanical force being applied to the input piston (3).

In the neutral (non-actuated) condition, fluid from the vehicle's hydraulic system flows unrestricted through the booster section. Hydraulic fluid enters the inlet port (1), flows across piston lands (2) on input piston (3), through boost piston flow ports (4) into chamber (6), and exits the booster through outlet port (7).

1. The booster operates on the principle of restricting fluid flow past piston lands (2) to create a higher pressure on the inlet side of boost piston (5) compared to the output side of boost piston (5). This is "pressure drop."

Due to flow and pressure drop characteristics of fluid in the booster section, the booster is designed to operate between 3 and 10 GPM unless otherwise noted.

1. It is likely that flow less than 3 GPM may not produce sufficient pressure drop for adequate boost.
2. Flow above 10 GPM may produce too much pressure drop through the booster section.
   A. Too much pressure drop through the booster can cause the booster section to hydraulically begin to "self energize" before the brake pedal is applied. This condition may also prevent the brake system from fully releasing.
   B. Flow over 10 GPM will waste hydraulic energy and cause the hydraulic system to operate at higher temperatures.

Forward Movement of Brake Pedal Until Fully Applied

(Refer to Figure 2)

As the operator applies the brake pedal, boost piston (3) begins to move forward and compress spring (10). Piston lands (2) begin to close causing restricted fluid flow and a build-up of pressure on inlet port side of boost piston (5).

This pressure moves boost piston (5) forward. Forward movement of boost piston (5) causes pistons (9, 11 & 12) to move forward and force fluid to the brakes.

1. The area of boost piston (5) is much larger than master cylinder piston (12), therefore, the fluid pressure being forced to the brakes is much higher than the pressure in boost chamber (8).

Brake system pressure in the master cylinder reacts against the area of reaction piston (9) and is transmitted mechanically to the brake pedal. This reaction provides the operator with a modulated "feel" of brake system pressure.

1. Pedal feed-back can be fine tuned to meet special application requirements by changing the diameter of reaction piston (9). The larger reaction piston (9), the higher the pedal effort necessary to achieve brake system pressure.

Continued forward pedal movement increases the restriction of flow at piston lands (2) and causes the increasing pressure in booster chamber (8) to move boost piston (5) forward. As pedal effort increases, this process continues until pressure in booster chamber (8) reaches the booster internal relief valve (13) setting. The relief valve pressure setting is preset at the factory.

With no additional forward movement of input piston (3), the pressure and spring forces will equalize and boost piston (5) will stop in this position. At this point the booster has reached the maximum boosting capability. Only the additional pedal effort by the operator can further increase brake pressure by mechanically moving the pistons forward.

Hydraulic system fluid flows through the booster section to outlet port (7) and through the remaining hydraulic circuit. Because the booster works on the principal of pressure drop, the resultant pressure of a power beyond device does not affect output pressure from the boosted master cylinder to the brakes. However, a relief valve must be present in the hydraulic system between the boosted master cylinder and power beyond device. This relief valve must open at a lower pressure than the system main relief valve to maintain the proper pressure drop.

Brake Pedal Released

(Refer to Figure 3)

When pedal force is removed from the input piston (3) the booster section and master cylinder section begin to release brake system pressure and return to the neutral (non-actuated) condition.

Springs (14 & 15) force input piston (3) back. Piston lands (2) and flow ports (4) open. Flow restriction is instantly removed and pressure in booster chamber (8) equalizes with the pressure in chamber (6).

Hydraulic system flow continues to enter inlet port (1) and exit outlet port (7).

The master cylinder section returns to the non-actuated position.

Callout Key

(1) Inlet Port
(2) Piston Lands
(3) Input Piston
(4) Flow Ports
(5) Boost Piston
(6) Chamber
(7) Outlet Port
(8) Booster Chamber
(9) Reaction Piston
(10) Spring
(11) Output Piston
(12) Master Cylinder Piston
(13) Internal Relief Valve
(14) Spring
(15) Spring

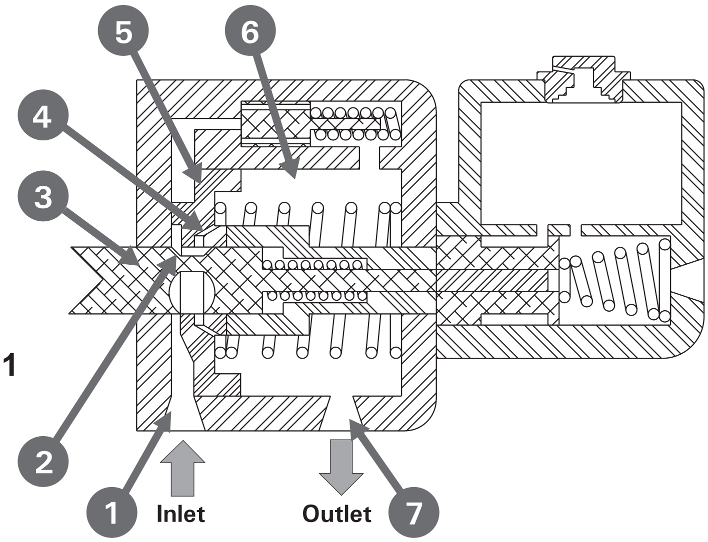


FIGURE 1

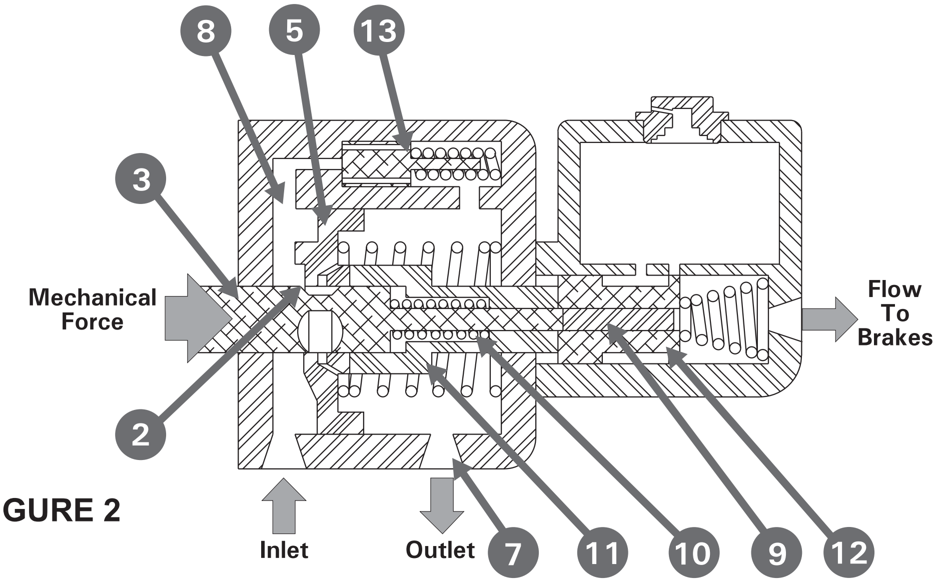


FIGURE 2

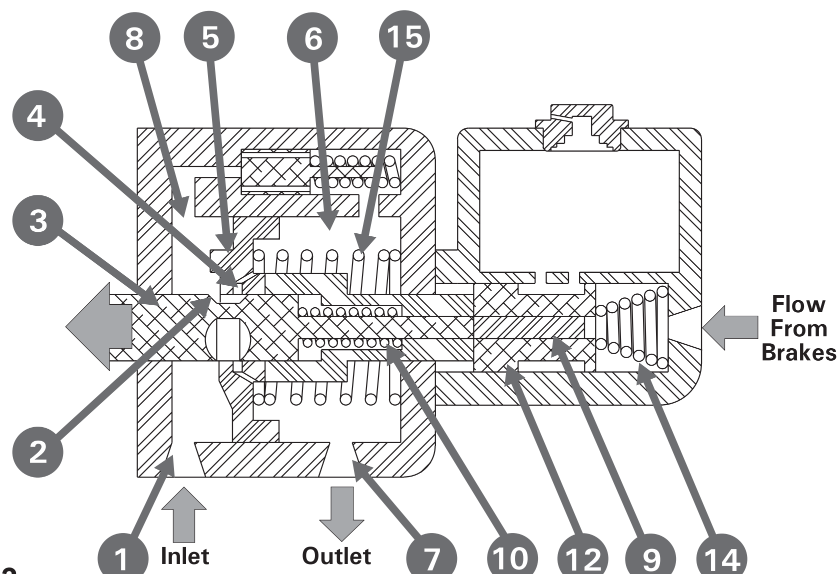


FIGURE 3

Operation of Master Cylinder Sections

Function of Residual Check Valves

The cylinders listed in this catalog are available with or without a residual check valve. Be sure to use the proper cylinder for your application.

Residual check valves are normally used in drum brake systems to hold a slight pressure (approximately 8-16 PSI) in the vehicle brake system while the brake pedal is released. This residual pressure is retained to flair the lip of the cup seal in the wheel cylinder to prevent leakage and/or air ingestion into the brake system.

Residual check valves are not used in disc brake systems. Residual pressure in a disc brake system will hold the brake pads in contact with the rotor disc, resulting in brake drag, over-heating of brake components, unnecessary wear and premature brake replacement.

Operation of Straight Bore Master Cylinders

(see pages 10 & 11)

(Refer to Figure 4)

The single piston straight bore type master cylinder has been proving its usefulness since the early 1930's and is still in extensive use.

With brakes completely released (no input force on brake pedal), the cylinder is at reservoir or atmospheric pressure. Initial brake actuation forces piston (1) and primary cup (2) down the cylinder bore (3) closing off the equalizing port (5). This completely seals fluid between the master cylinder and the brake cylinder.

The reaction piston (6) is forced against the booster section input piston and generates a modulated pedal feel. This force is proportional to the output pressure of the master cylinder.

Continued brake pedal movement will now cause an increase in fluid pressure, transmitted to the brake cylinders. Releasing the force on the brake pedal allows fluid to flow back to the cylinder bore (3) and ultimately to the reservoir (4).

Callout Key

(1) Piston
(2) Primary Cup
(3) Cylinder Bore
(4) Reservoir
(5) Equalizing Port
(6) Reaction Piston

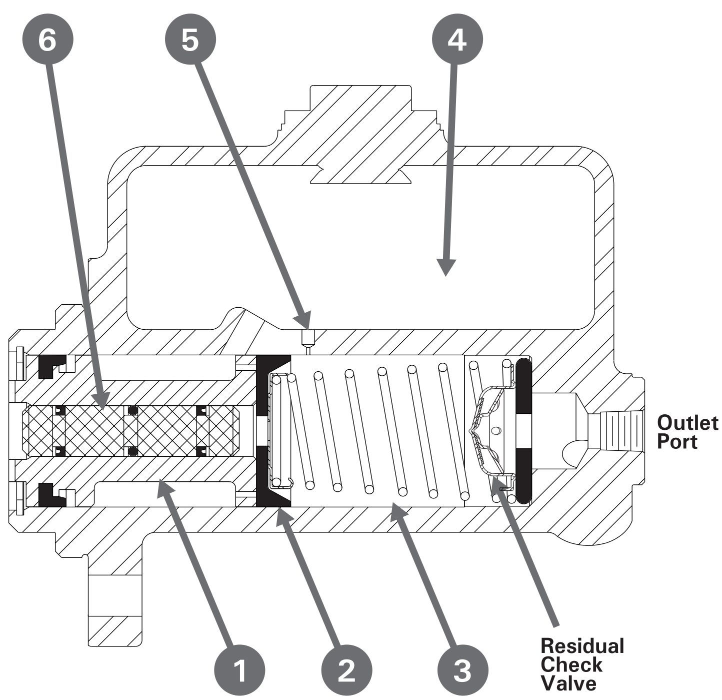


FIGURE 4

Operation of Master Cylinder Sections

Operation of Tandem Master Cylinder

(see pages 14 & 15)

(Refer to Figure 5)

The tandem master cylinder was developed as a result of regulations governing brake systems on highway vehicles. Many off-road vehicles also use this type cylinder. These cylinders provide two independent master cylinder sections in a common housing.

When the cylinder is at rest, the primary and secondary sections are directly communicated to the reservoirs, allowing, to a degree, purging of residual air and pressure equalization.

Initial brake actuation forces front piston (1) to contact the primary seat (2) pressurizing the primary bore (9). As pressure increases, the secondary piston (8) is hydraulically driven forward. The secondary stem (5) contacts the secondary seat (6) and the secondary bore (7) is pressurized. Both bores are equally pressurized as the cylinder is stroked.

The reaction piston (11) is forced against the booster section input piston and generates a modulated pedal feel. This force is proportional to the pressure in primary bore (9). Since there are no equalizing ports for the high pressure cups to pass, primary check valve (3) and secondary check valve (4) open during return stroke of cylinder allowing a rapid smooth return of both pistons. Releasing the force on the brake pedal allows fluid to flow back to the primary and secondary bores (9 & 7) and back to the reservoir.

In the event of a primary section malfunction, the primary piston (10) will mechanically drive the secondary piston (8) forward. The foot pedal will drop due to the approximately 0.7 inch of internal piston travel before secondary system pressure is reached.

If a secondary section malfunction occurs, the primary piston (10) will hydraulically drive the secondary piston (8) until it bottoms out. The primary bore (9) will then pressurize upon continued pedal travel.

Callout Key

(1) Front Piston
(2) Primary Seat
(3) Primary Check Valve
(4) (Secondary Check Valve
(5) Secondary Stem
(6) Secondary Seat
(7) Secondary Bore
(8) Secondary Piston
(9) Primary Bore
(10) Primary Piston
(11) Reaction Piston

Residual Check Valve and Outlet Ports are not shown.

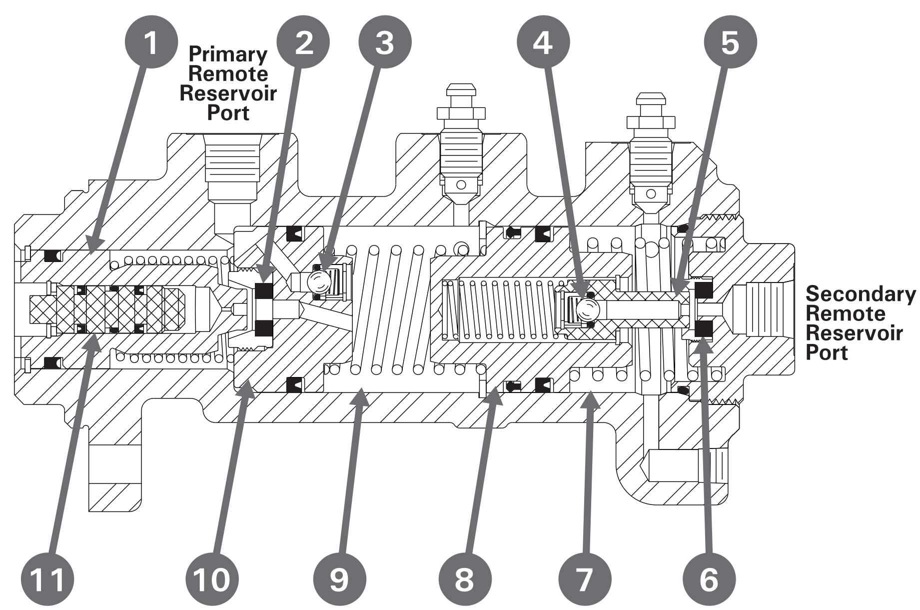


FIGURE 5

Operation of Master Cylinder Sections

Operation of Straight Bore Master Cylinders (stem seal type)

(see pages 12 & 13)

(Refer to Figure 6)

By eliminating the equalizing port normally found on master cylinders, this cylinder offers simplicity, ease of bleeding and versatility. The lack of a compensating port allows the cylinder to be used in a broad range of applications indiscriminative of volumetric output.

With no input force on brake pedal the cylinder is at reservoir or atmospheric pressure. Initial brake actuation forces secondary piston (2) into the contact seat (3). Continuation of brake actuation force will begin to pressurize the fluid at the output port. The pressure is communicated to the reaction piston (1) and the resulting force is directed back through the booster section input piston and to the vehicle pedal. This action provides the operator with modulated pedal feel proportional to the system pressure.

Upon release of the brake pedal, the primary piston (4) returns and bottoms out on the cylinder housing.

Fluid displaced from the reservoir is now forced back into the reservoir. The secondary piston (2) is forced back to the retaining ring and the primary seat (3) is open to reservoir or atmospheric pressure.

Callout Key

(1) Reaction Piston
(2) Secondary Piston
(3) Seat
(4) Primary Piston

Residual Check Valve is not shown.

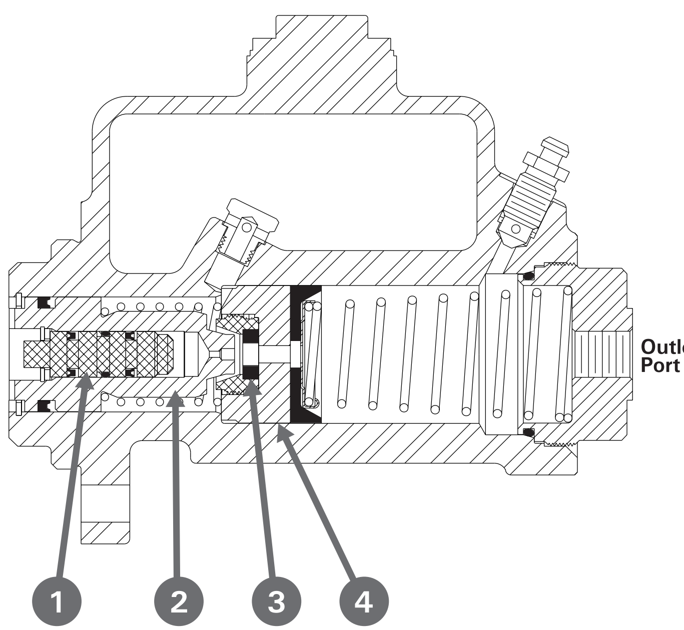


FIGURE 6

Operation of Master Cylinder Sections

Operation of Two-Stage Master Cylinders

(see pages 16 & 17)

(Refer to Figure 7)

With no input force from the brake pedal, the cylinder fluid is at reservoir pressure throughout. The relief valve piston (1) is closed, reservoir port (2) is open and high pressure piston (9) is open at seat (11).

Initial brake pedal actuation forces the low pressure piston (5) to move the low pressure cup (3) past the reservoir port (2). Continued pedal movement causes fluid in the low pressure bore (10) and high pressure bore (6) to become pressurized, forcing fluid to exit the outlet port. The reaction piston (4) is forced against the booster section input piston and generates modulated brake pedal feel. This force is proportional to the pressure in high pressure bore (6). Continued pedal movement will force the high pressure piston (9) against seat (11). The pressurized fluid will then be directed over the high pressure cup (7), through flow-through hole (8) and out through outlet port.

Low pressure displacement will continue until pressure in the brake system is greater than the relief valve pressure setting. Pressure is sensed at the outlet port and communicated to the relief valve piston (1) via the tube assembly (12).

When the relief valve piston (1) opens, pressurized fluid in low pressure bore (10) flows directly to reservoir.

Due to the pressure drop in the low pressure bore (10) the high pressure cup (7) flares, sealing any flow from low pressure bore (10) to high pressure bore (6). At the same time high pressure piston (9) fully seals to seat (11). Further cylinder displacement to outlet port is continued by the flow from high pressure bore (6) only.

Releasing the force on the brake pedal allows cylinder components to return to a static position and fluid to flow back to reservoir.

Callout Key

(1) Relief Valve Piston
(2) Reservoir Port
(3) Low Pressure Cup
(4) Reaction Piston
(5) Low Pressure Piston
(6) High Pressure Bore
(7) High Pressure Cup
(8) Flow Through Hole
(9) High Pressure Piston
(10) Low Pressure Bore
(11) Seat
(12) Tube Assembly

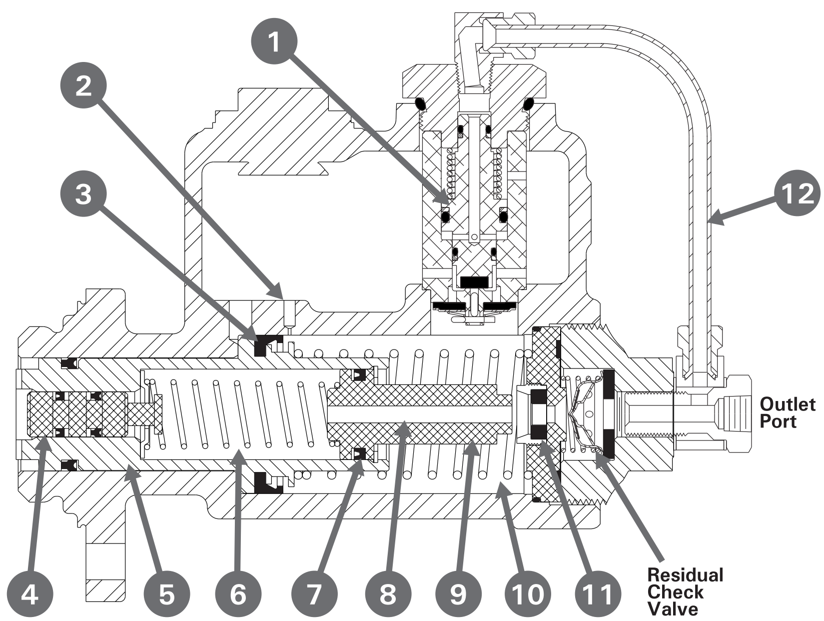
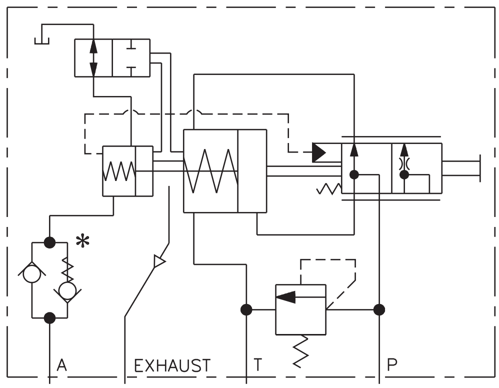


FIGURE 7

Boosted Straight Bore Master Cylinders

Style A (diaphragm reservoir) | **Style B** (dual filler caps) | **Style C** (single filler cap)

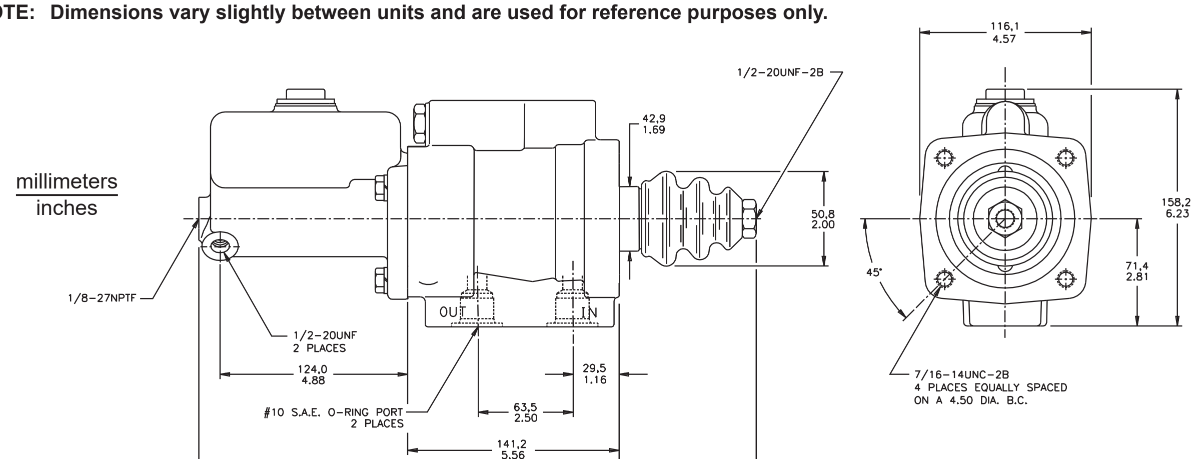


* Residual valve used where required.
Exhaust venting hole is normally in down position to prevent moisture contamination.

FEATURES

- Provides natural pedal "feel" through hydraulic reaction
- Completely hydraulic - no vacuum or air assist required

NOTE: Dimensions vary slightly between units and are used for reference purposes only.

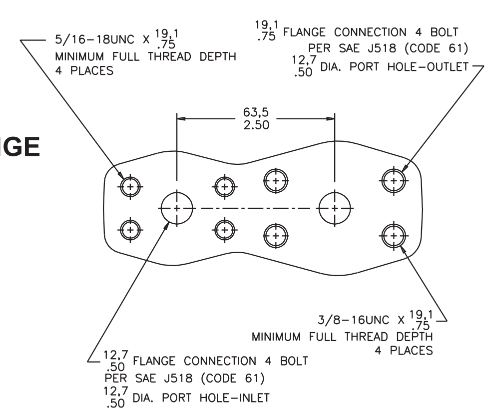


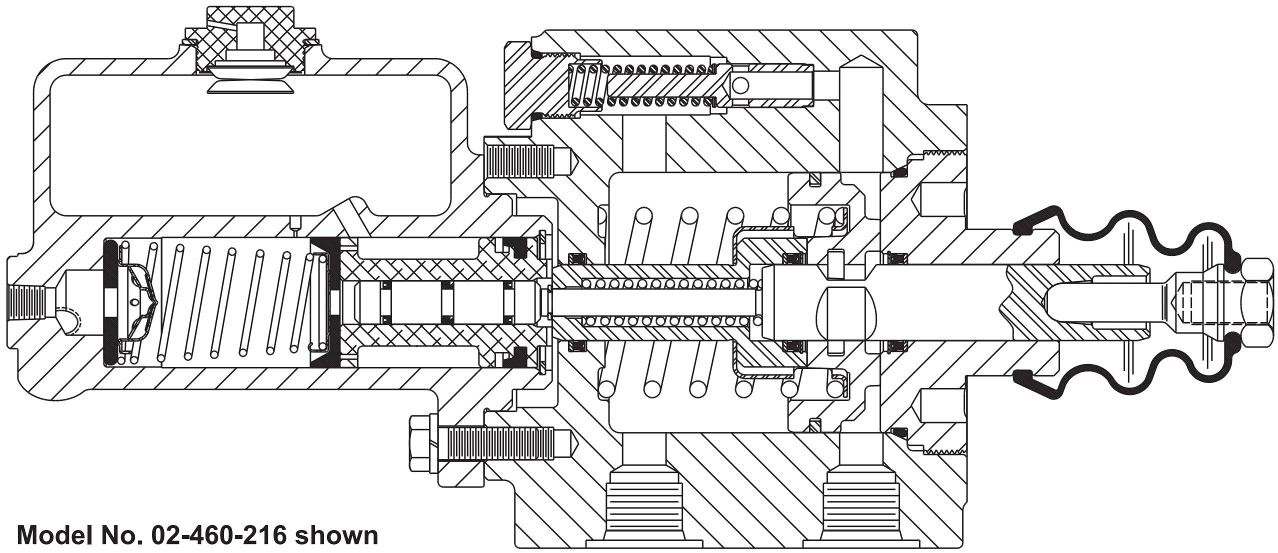
Model No. 02-460-216 shown

SPLIT FLANGE MODELS

02-460-218

02-460-308





Model No. 02-460-216 shown

SPECIFICATIONS

NOTE: While some model numbers may have identical specifications, there may be differences in fittings, port sizes and filler plugs. Contact ZF Off-Highway Solutions Minnesota Inc. for more information.

Model Number	Style (see top of page 10)	Brake Line Pressure (PSI)	Master Cylinder Bore Diameter	Master Cylinder Fluid Displacement	Push Rod Force with Boosted Power	Push Rod Force for 500 PSI without Boosted Power	Booster Pressure Differential at Maximum Brake Line Pressure	Master Cylinder Fluid Type	Uses a Residual Check Valve
02-460-216	C	0 - 1500	1.500 in	2.40 in^3	375 lb @ 1500 PSI	960 lb	360 PSI @ 8 GPM	BF	Yes
+ ⁎ 02-460-218	C	0 - 1365	1.500 in	2.40 in^3	700 lb @ 1365 PSI	960 lb	280 PSI @ 6 GPM	BF	Yes
02-460-248	C	0 - 1500	1.250 in	1.67 in^3	375 lb @ 1500 PSI	690 lb	260 PSI @ 10 GPM	BF	Yes
02-460-264	B	0 - 900	1.750 in	3.27 in^3	500 lb @ 900 PSI	1275 lb	290 PSI @ 5 GPM	BF	Yes
02-460-266	B	0 - 1500	1.750 in	3.27 in^3	375 lb @ 1500 PSI	1275 lb	535 PSI @ 6 GPM	BF	Yes
02-460-268	B	0 - 1500	1.750 in	3.27 in^3	375 lb @ 1500 PSI	1275 lb	535 PSI @ 6 GPM	BF	No
02-460-280	A	0 - 1500	1.500 in	2.40 in^3	375 lb @ 1500 PSI	960 lb	360 PSI @ 8 GPM	BF	Yes
+ ⁎ 02-460-308	C	0 - 1500	1.500 in	2.40 in^3	375 lb @ 1500 PSI	960 lb	365 PSI @ 10 GPM	BF	Yes
● ⁎ 02-460-334	C	0 - 900	1.500 in	2.40 in^3	260 lb @ 900 PSI	960 lb	245 PSI @ 10 GPM	BF	Yes
02-460-416	C	0 - 1800	1.500 in	2.40 in^3	910 lb @ 1800 PSI	960 lb	365 PSI @ 10 GPM	BF	Yes
02-460-478	C	0 - 1500	1.500 in	2.40 in^3	375 lb @ 1500 PSI	960 lb	360 PSI @ 8 GPM	BF	Yes
02-461-216	C	0 - 1500	1.500 in	2.40 in^3	375 lb @ 1500 PSI	960 lb	360 PSI @ 8 GPM	BF	No
02-461-248	C	0 - 1500	1. 250 in	1.67 in^3	375 lb @ 1500 PSI	690 lb	260 PSI @ 10 GPM	BF	No
♦ 02-461-480	B	0 - 1500	2.250 in	5.41 in^3	375 lb @ 1500 PSI	2060 lb	910 PSI @ 7 GPM	BF	No

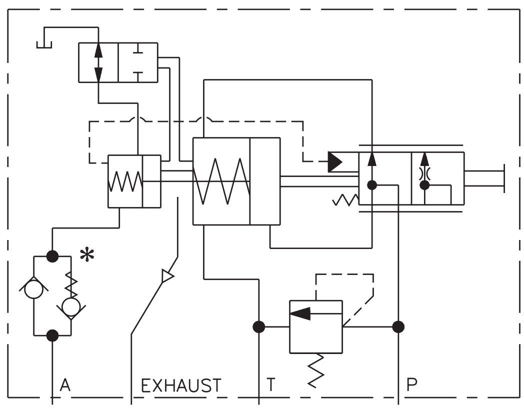
NOTES:

All model numbers have a flow capacity of 3 to 10 GPM unless noted otherwise.
All model numbers have a main hydraulic system pressure of 0 to 2000 PSI unless noted otherwise.
All model numbers have a 1.62 inch push rod travel unless noted otherwise.
BF = DOT 3, 4, 5 and 5.1 brake fluid.

⁎ Flow capacity is 3 to 12 GPM.
● Main hydraulic system pressure is 0 - 3000 PSI.
+ Split flange (see details on page 10).
♦ Master cylinder has a bleeder screw. It appears similar to Style A on page 12.

Boosted Straight Bore Master Cylinders

(stem seal type)



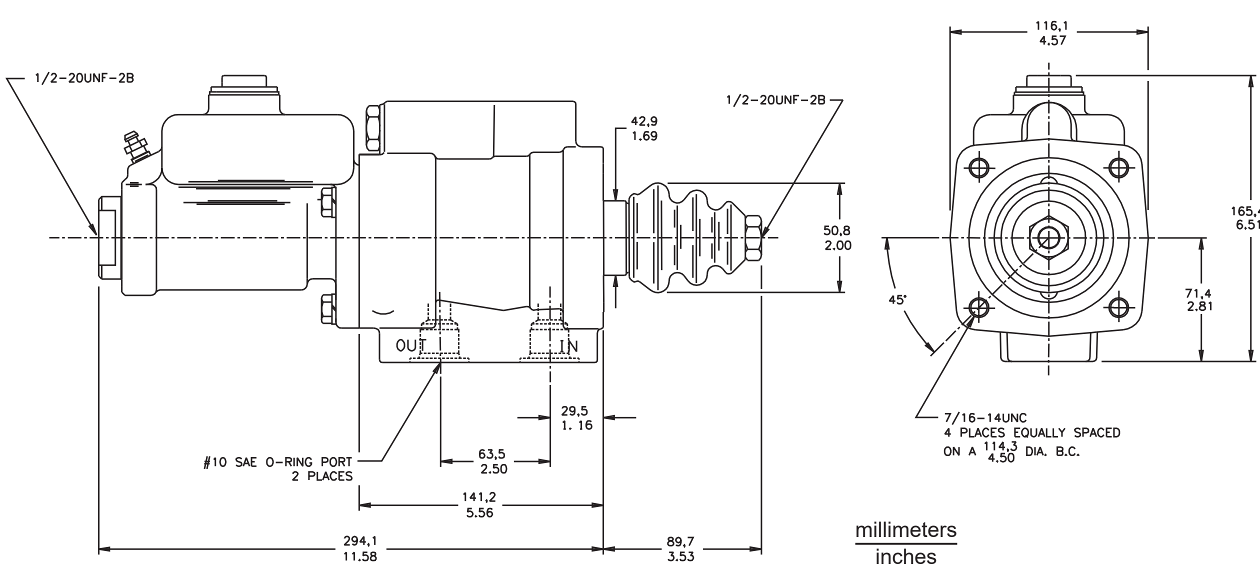
∗ Residual valve used where required.
Exhaust venting hole is normally in down position to prevent moisture contamination.

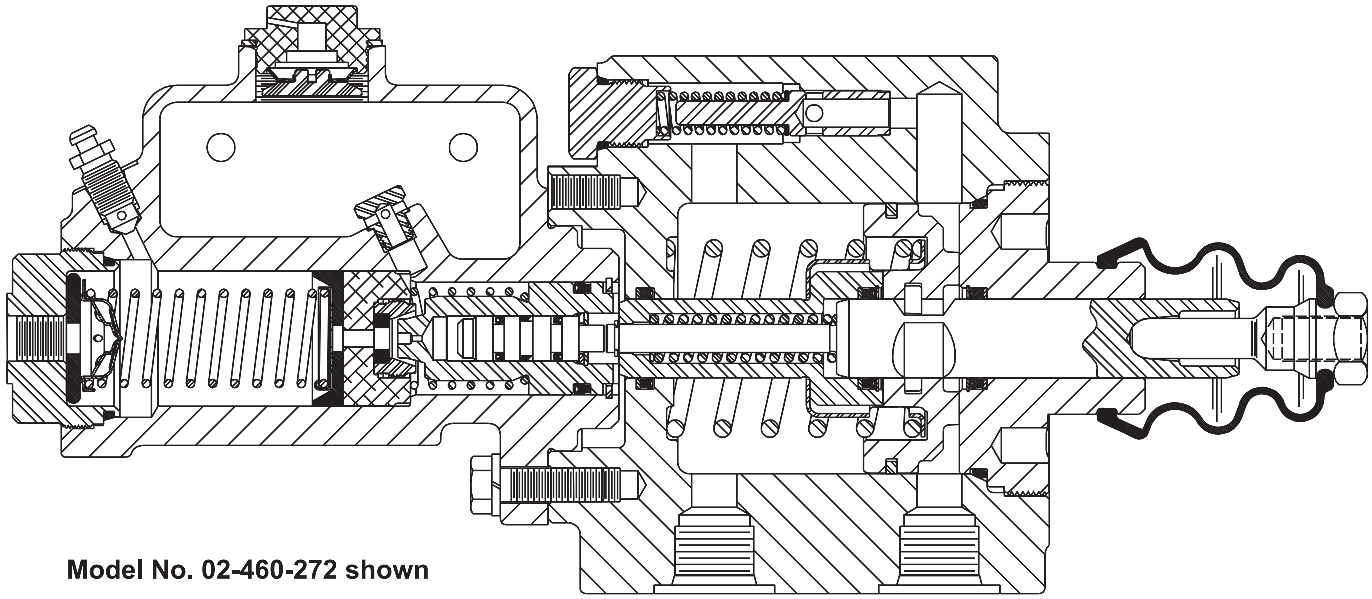
FEATURES

- Provides natural pedal "feel" through hydraulic reaction
- Completely hydraulic - no vacuum or air assist required
- May be used for spring brake applications
- Easy to bleed

NOTE: Dimensions vary slightly between units and are used for reference purposes only.

Model No. 02-460-272 shown





Model No. 02-460-272 shown

SPECIFICATIONS

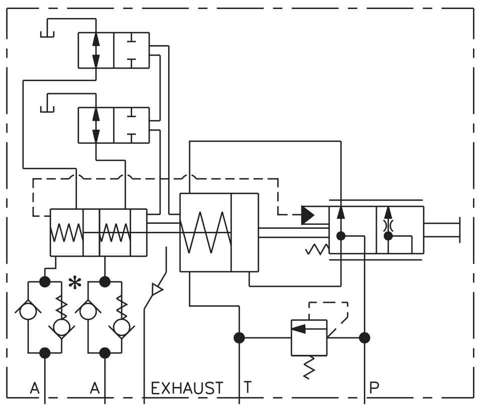
NOTE: While some model numbers may have identical specifications, there may be differences in fittings, port sizes and filler plugs. Contact ZF Off-Highway Solutions Minnesota Inc. for more information.

Model Number	Brake Line Pressure (PSI)	Master Cylinder Bore Diameter	Master Cylinder Fluid Displacement	Push Rod Force with Boosted Power	Push Rod Force for 500 PSI without Boosted Power	Booster Pressure Differential at Maximum Brake Line Pressure	Master Cylinder Fluid Type	Uses a Residual Check Valve
02-460-390	0 - 1500	1.250 in	1.67 in^3	200 lb @ 1500 PSI	690 lb	285 PSI @ 10 GPM	BF	No
02-460-394	0 - 1150	1.500 in	2.40 in^3	300 lb @ 1150 PSI	960 lb	290 PSI @ 8 GPM	HO	No
02-460-396	0 - 1150	1.500 in	2.40 in^3	300 lb @ 1150 PSI	960 lb	290 PSI @ 8 GPM	BF	No
02-460-398	0 - 1650	1.500 in	2.40 in^3	420 lb @ 1650 PSI	960 lb	420 PSI @ 10 GPM	BF	No
02-460-428	0 - 1350	1.250 in	1.67 in^3	203 lb @ 1350 PSI	690 lb	240 PSI @ 10 GPM	BF	Yes
02-460-430	0 - 1550	1.500 in	2.40 in^3	400 lb @ 1550 PSI	960 lb	370 PSI @ 10 GPM	HO	No
02-460-468	0 - 1600	1.750 in	3.27 in^3	805 lb @ 1600 PSI	1275 lb	610 PSI @ 10 GPM	BF	Yes
02-460-496	0 - 900	1.500 in	2.40 in^3	260 lb @ 900 PSI	960 lb	240 PSI @ 10 GPM	HO	Yes
02-460-626	0 - 1500	1.250 in	1.67 in^3	375 lb @ 1500 PSI	690 lb	260 PSI @ 10 GPM	BF	Yes

NOTES:
All model numbers have a flow capacity of 3 to 10 GPM unless noted otherwise.
All model numbers have a main hydraulic system pressure of 0 to 2000 PSI unless noted otherwise.
All model numbers have a 1.62 inch push rod travel unless noted otherwise.
BF = DOT 3, 4, 5 and 5.1 brake fluid.   HO = mineral base hydraulic oil.

Boosted Tandem Straight Bore Master Cylinders

(stem seal type)



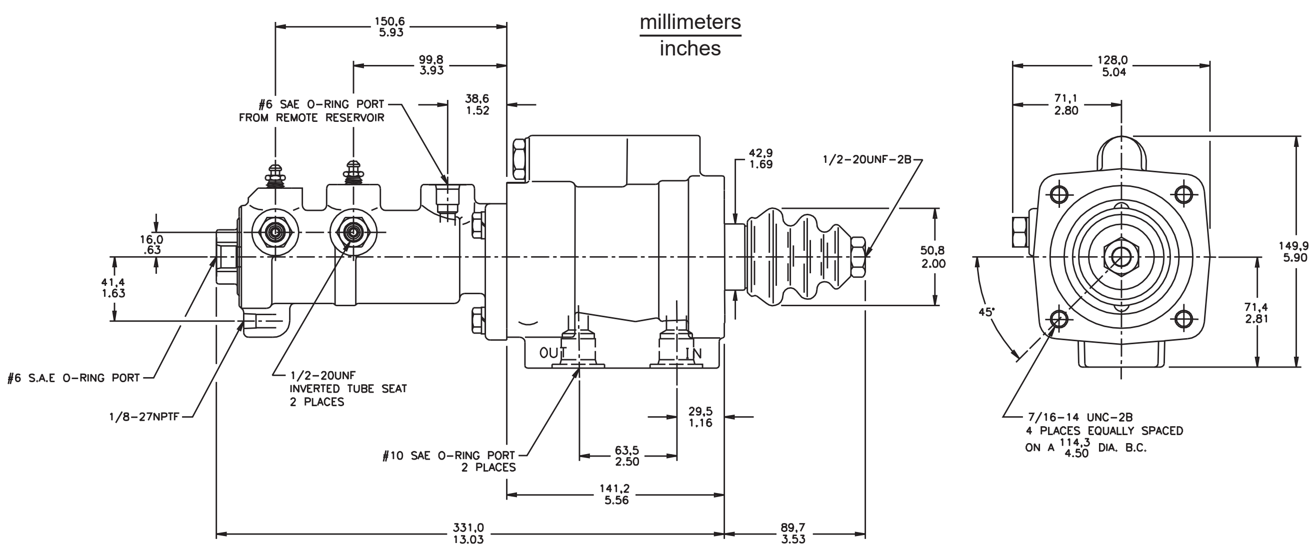
⁎ Residual valve used where required.
Exhaust venting hole is normally in down position to prevent moisture contamination.

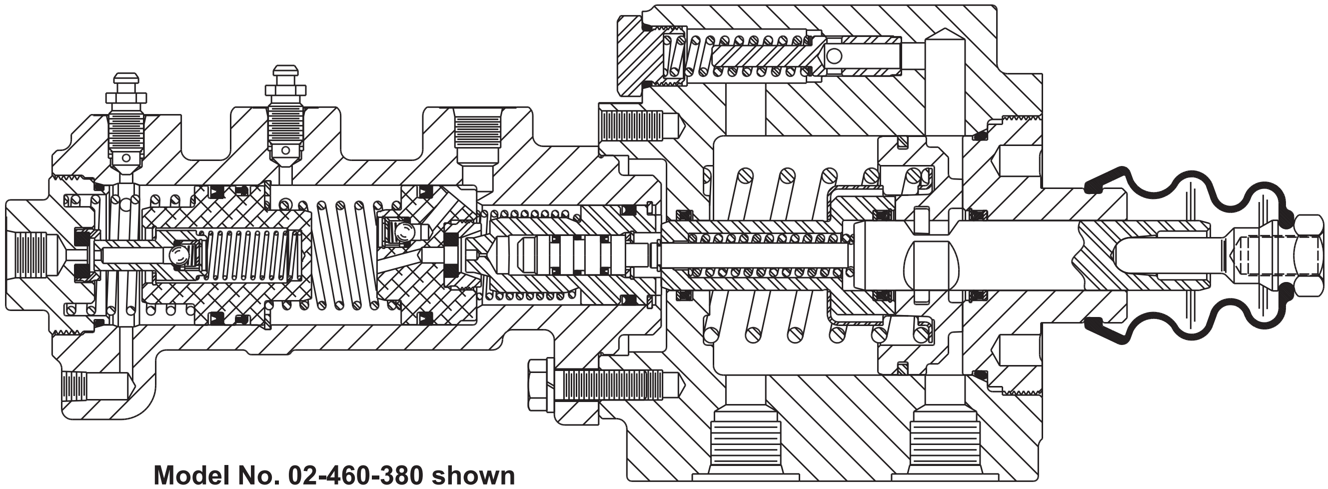
FEATURES

- Provides natural pedal "feel" through hydraulic reaction
- Two independent master cylinders and reservoir ports in a common housing
- Provides braking in the event either the front or rear brakes become inoperative
- Completely hydraulic - no vacuum or air assist required
- Uses a remote fluid reservoir for ease of monitoring fluid level

NOTE: Dimensions vary slightly between units and are used for reference purposes only.

Model No. 02-460-380 shown





Model No. 02-460-380 shown

SPECIFICATIONS

NOTE: While some model numbers may have identical specifications, there may be differences in fittings, port sizes and filler plugs. Contact ZF Off-Highway Solutions Minnesota Inc. for more information.

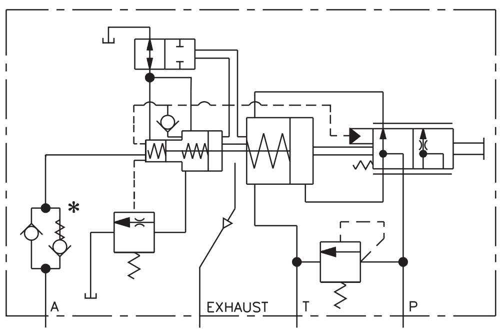
Model Number	Brake Line Pressure (PSI)	Master Cylinder Bore Diameter	Master Cylinder Fluid Displacement	Push Rod Force with Boosted Power	Push Rod Force for 500 PSI without Boosted Power	Booster Pressure Differential at Maximum Brake Line Pressure	Master Cylinder Fluid Type	Uses Residual Check Valves
02-460-360	0 - 900	1.750 in	1.62 - 1.62 in^3 50 - 50 split	500 lb @ 900 PSI	1312 lb	290 PSI @ 5 GPM	BF	Yes
● 02-460-380	0 - 1600	1.750 in	1.92 - 1.31 in^3 60 - 40 split	420 lb @ 1600 PSI	1312 lb	535 PSI @ 10 GPM	BF	Yes
● 02-460-404	0 - 1550	1.750 in	1.62 - 1.62 in^3 50 - 50 split	390 lb @ 1550 PSI	1312 lb	535 PSI @ 10 GPM	BF	Yes
02-460-410	0 - 1230	1.750 in	1.62 - 1.62 in^3 50 - 50 split	350 lb @ 1230 PSI	1312 lb	420 PSI @ 10 GPM	BF	No
02-460-476	0 - 900	1.750 in	1.62 - 1.62 in^3 50 - 50 split	270 lb @ 900 PSI	1312 lb	320 PSI @ 10 GPM	HO	No
02-460-494	0 - 550	1.750 in	1.62 - 1.62 in^3 50 - 50 split	295 lb @ 550 PSI	1312 lb	185 PSI @ 10 GPM	HO	No
02-460-602	0 - 900	1.750 in	1.62 - 1.62 in^3 50 - 50 split	490 lb @ 900 PSI	1312 lb	320 PSI @ 10 GPM	HO	No
● 02-461-404	0 - 1550	1.750 in	1.62 - 1.62 in^3 50 - 50 split	390 lb @ 1550 PSI	1312 lb	535 PSI @ 10 GPM	BF	No

NOTES:

All model numbers have a flow capacity of 3 to 10 GPM unless noted otherwise.
All model numbers have a main hydraulic system pressure of 0 to 2000 PSI unless noted otherwise.
All model numbers have a 1.62 inch push rod travel unless noted otherwise.
BF = DOT 3, 4, 5 and 5.1 brake fluid.   HO = mineral base hydraulic oil.

* Master cylinder has integral reservoirs.
● Main hydraulic system pressure is 0 - 3000 PSI.
▲ Push rod travel is 1.49 inch.
■ Only the secondary outlet port has residual check valve.

Boosted Two-Stage Master Cylinders



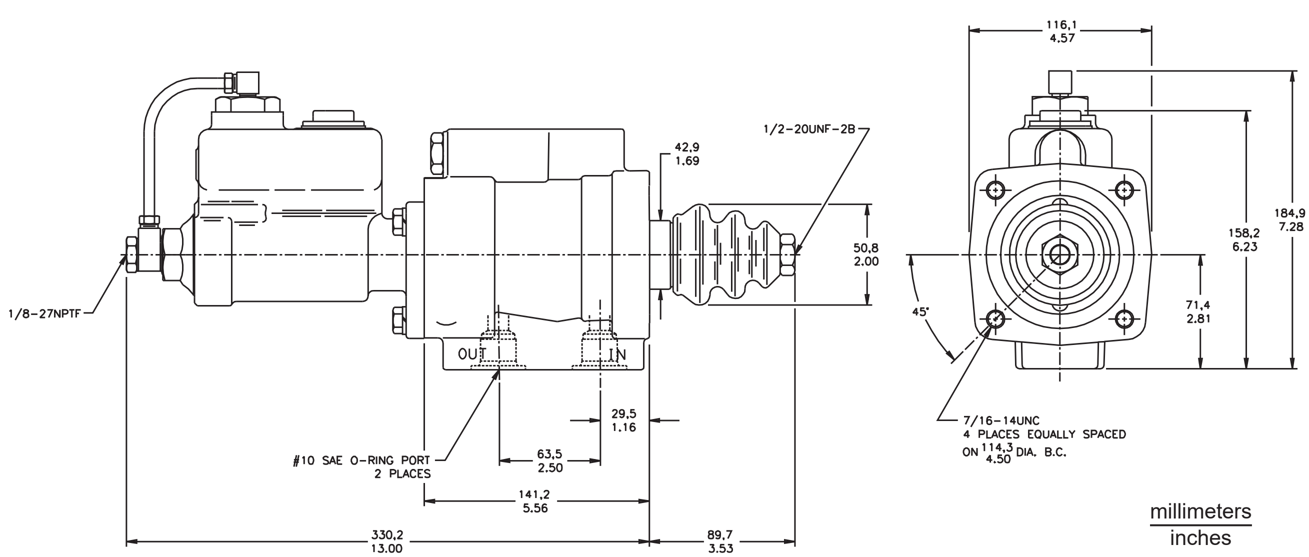
* Residual valve used where required.
Exhaust venting hole is normally in down position to prevent moisture contamination.

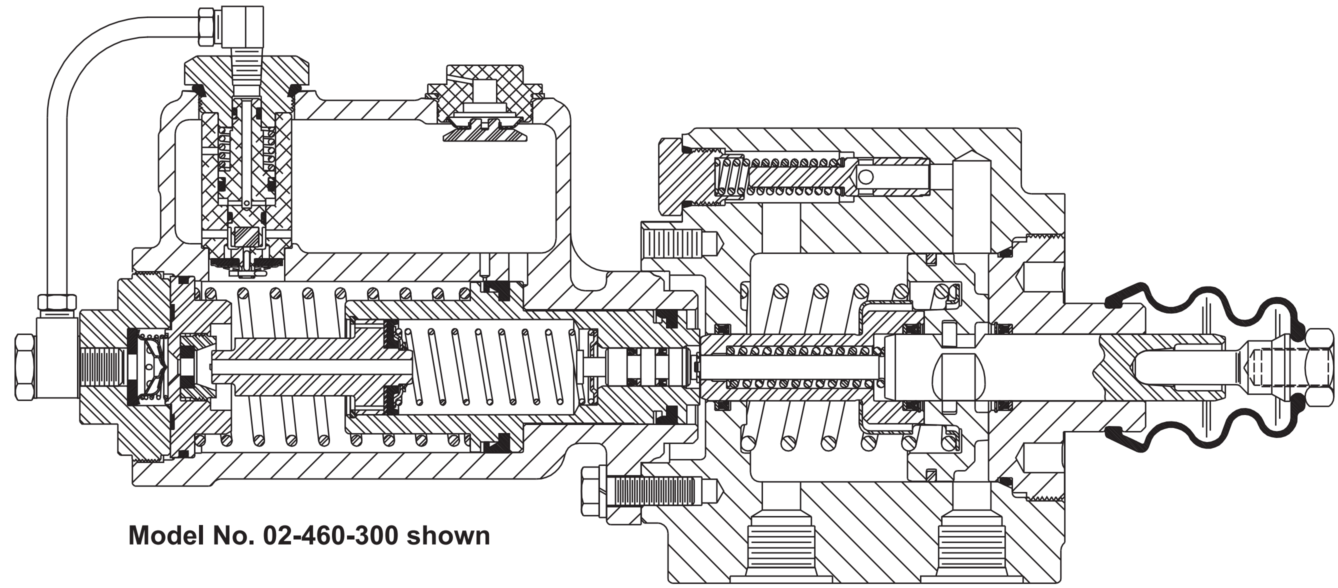
FEATURES

- Provides natural pedal "feel" through hydraulic reaction
- Completely hydraulic - no vacuum or air assist needed
- Provides high brake system pressure in the event of inadequate booster pressure

NOTE: Dimensions vary slightly between units and are used for reference purposes only.

Model No. 02-460-300 shown





Model No. 02-460-300 shown

SPECIFICATIONS

NOTE: While some model numbers may have identical specifications, there may be differences in fittings, port sizes and filler plugs. Contact ZF Off-Highway Solutions Minnesota Inc. for more information.

Model Number	Brake Line Pressure (PSI)	Master Cylinder Bore Diameter	Master Cylinder Fluid Displacement	Push Rod Force with Boosted Power	Push Rod Force for 500 PSI without Boosted Power	Booster Pressure Differential at Maximum Brake Line Pressure	Master Cylinder Fluid Type	Uses a Residual Check Valve
02-460-276	0 - 1500	1.750 in / 1.000 in	1.1 - 2.2 in^3	375 lb @ 1500 PSI	470 lb	135 PSI @ 8 GPM	BF	Yes
02-460-294	0 - 1500	1.750 in / 1.125 in	1.4 - 2.3 in^3	375 lb @ 1500 PSI	570 lb	185 PSI @ 8 GPM	BF	Yes
02-460-346	0 - 1150	1.750 in / 1.125 in	1.4 - 2.3 in^3	460 lb @ 1150 PSI	570 lb	119 PSI @ 3.5 GPM	BF	Yes
02-460-432	0 - 1500	1.750 in / 0.875 in	0.9 - 3.5 in^3	215 lb @ 1500 PSI	375 lb	122 PSI @ 3 GPM	HO	No
02-460-450	0 - 1500	1.750 in / 1.000 in	1.1 - 2.2 in^3	130 lb @ 1500 PSI	470 lb	170 PSI @ 8 GPM	BF	Yes

NOTES:

All model numbers have a flow capacity of 3 to 10 GPM unless noted otherwise.
All model numbers have a main hydraulic system pressure of 0 to 2000 PSI unless noted otherwise.
All model numbers have a 1.62 inch push rod travel unless noted otherwise.
BF = DOT 3, 4, 5 and 5.1 brake fluid. HO = mineral base hydraulic oil.

Hydraulic Power Brake Actuator

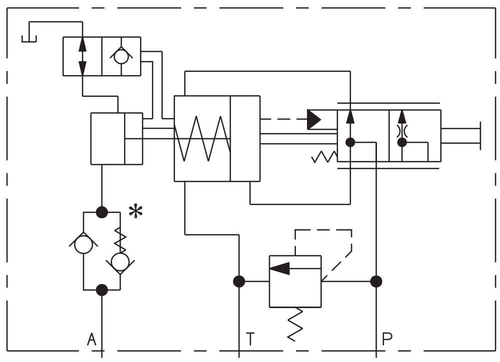
DESCRIPTION AND OPERATION

The compact size Hydraulic Power Brake Actuator is designed for use with vehicles that are equipped with an open center hydraulic system that can supply 0.7 to 4 GPM at 335 PSI to obtain the set brake limit pressure.

The Hydraulic Power Brake Actuator combines a hydraulically boosted power section with a master cylinder section in a single unit. This valve uses mineral based hydraulic oil in both the booster and master cylinder sections. The master cylinder section is separate from the booster portion so an alternate fluid such as transmission oil can be used for the brakes. However, DOT brake fluid cannot be used.

A hydraulic feedback system within the valve gives the operator pedal feel directly proportional to the brake pressure, thus providing excellent modulation.

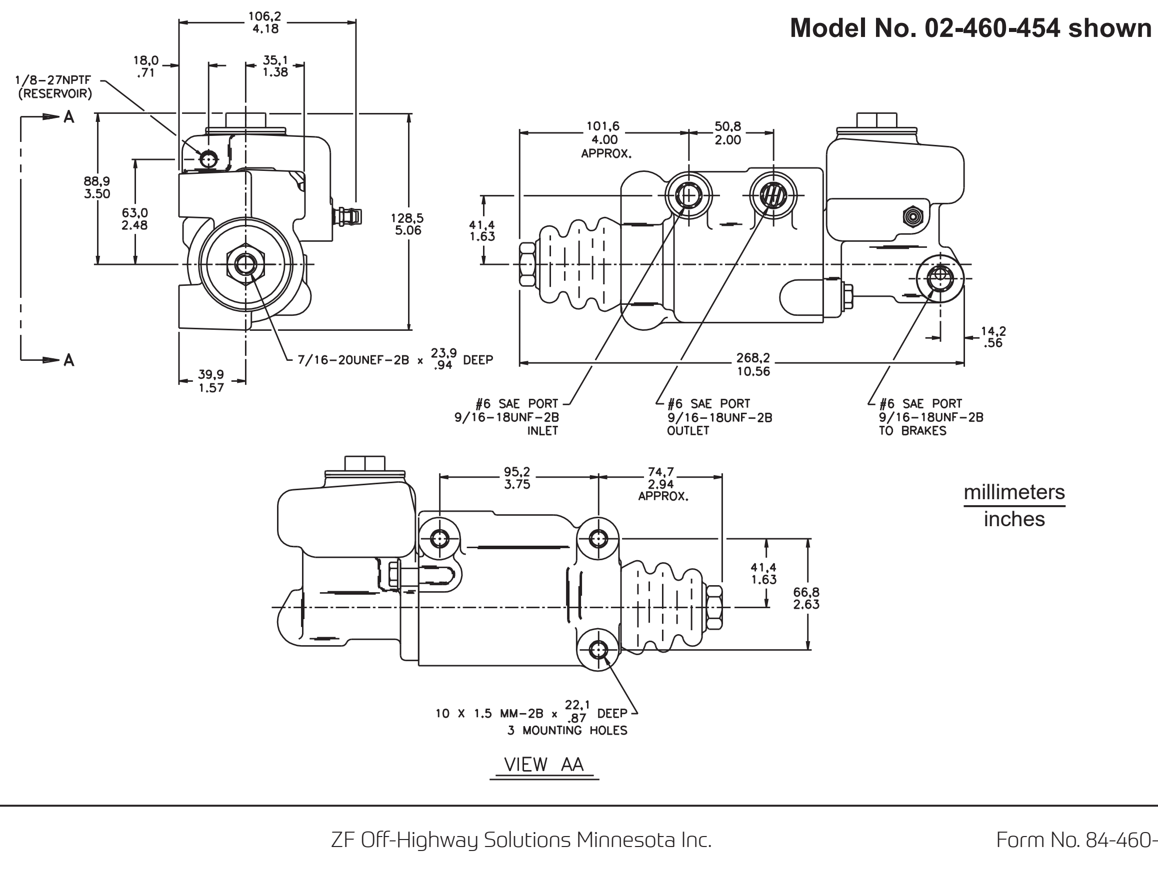
The master cylinder can be operated manually through the booster during power-off conditions. Brake pressure developed without boost assist will depend on the push rod force applied.

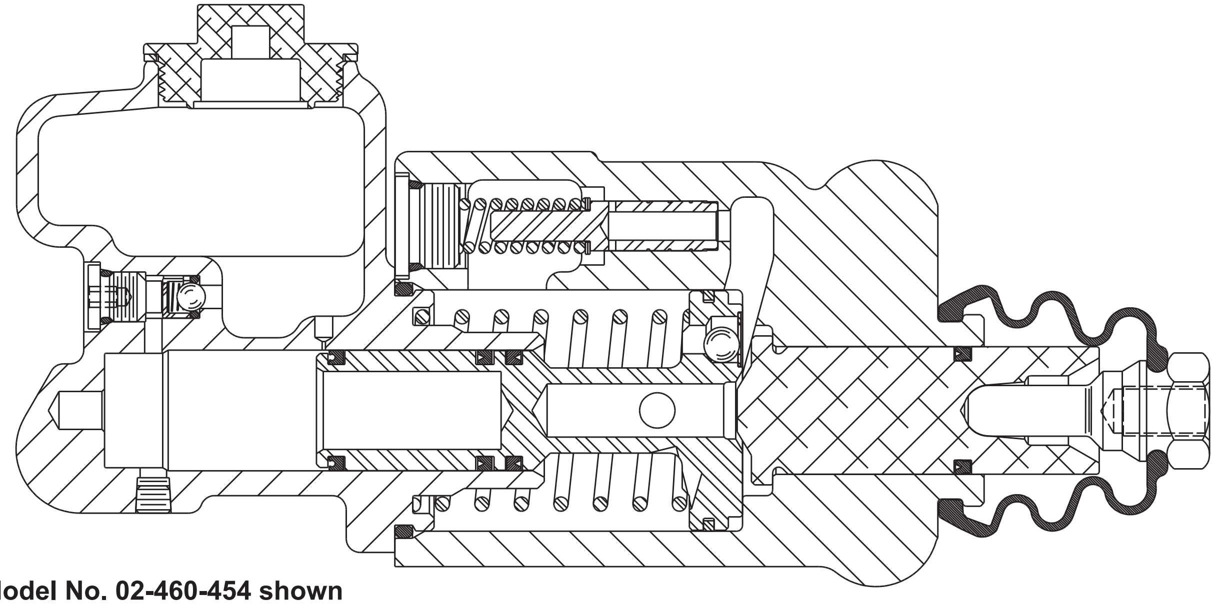


* Residual valve used where required.

NOTE: Dimensions vary slightly between units and are used for reference purposes only.

Model No. 02-460-454 shown





Model No. 02-460-454 shown

SPECIFICATIONS

NOTE: While some model numbers may have identical specifications, there may be differences in fittings, port sizes and filler plugs. Contact ZF Off-Highway Solutions Minnesota Inc. for more information.

Model Number	Brake Line Pressure (PSI)	Master Cylinder Bore Diameter	Master Cylinder Fluid Displacement	Push Rod Force with Boosted Power	Push Rod Force for 500 PSI without Boosted Power	Booster Pressure Differential at Maximum Brake Line Pressure	Master Cylinder Fluid Type	Uses Residual Check Valve
02-460-454	1100	1.061 in	1.1 in^3	250 lb @ 1100 PSI	510 lb	335 PSI	HO	No
02-460-488	700	1.061 in	1.1 in^3	175 lb @ 700 PSI	510 lb	210 PSI	HO	Yes

NOTES:
All model numbers have a 1.3 inch push rod travel unless noted otherwise.
HO = mineral base hydraulic oil.

Boosted Open Center Master Cylinder

DESCRIPTION

The Open Center Master Cylinder, also called Open Center Valve, permits the addition of a power braking system to vehicles which are equipped with other hydraulic power devices such as power steering or implements.

Through the use of the boosted open center master cylinder, power from the main open center hydraulic system can be used to operate the vehicle's brakes, eliminating the need of any other power brake unit.

Design of the boosted open center master cylinder insures a natural pedal feel. The reaction of the pedal against the driver's foot is directly proportional to the hydraulic pressure in the wheel cylinders which actuate the brakes.

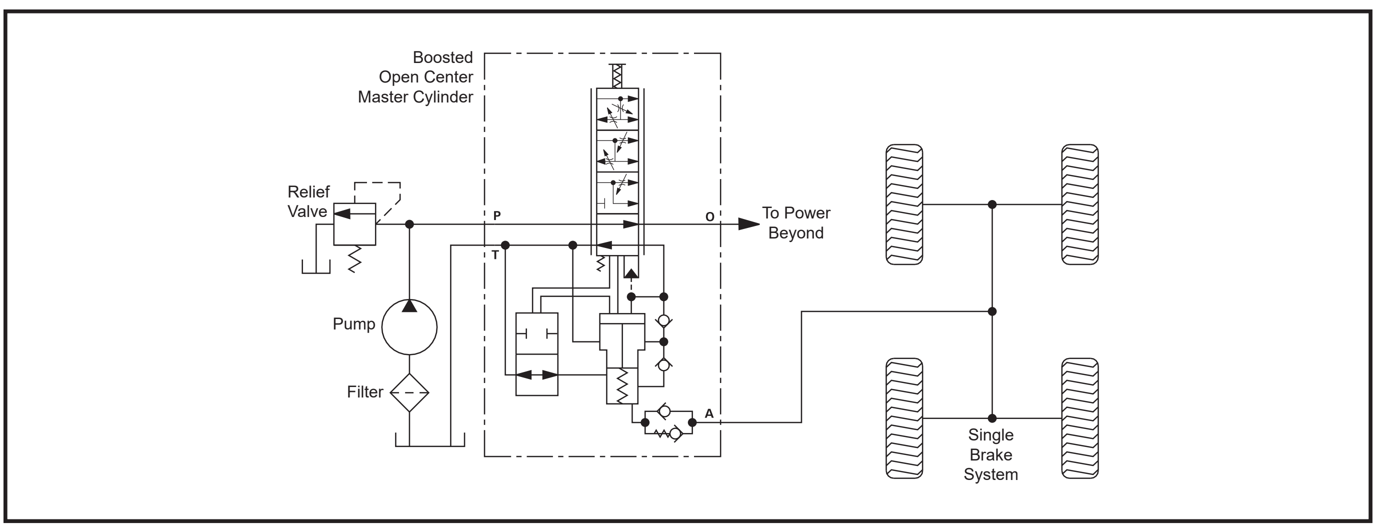
The boosted master cylinder permits the brake system to develop up to double the amount of hydraulic pressure present in the main hydraulic system. For example, 52 bar (750 PSI) in the main system can deliver 103 bar (1500 PSI) to the brake cylinders.

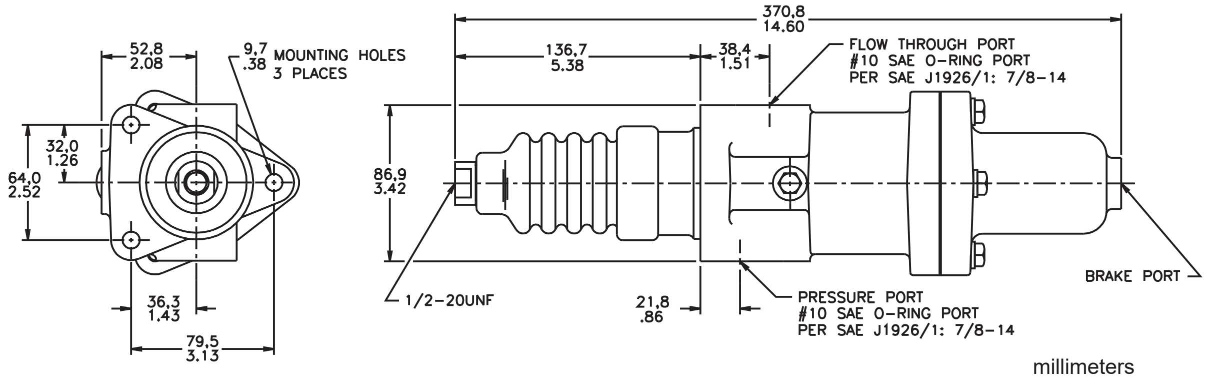
In the event hydraulic system pressure is lost, the master cylinder can be actuated mechanically through the booster at an unassisted level.

FEATURES

- Eliminates the need of a separate power brake unit
- Provides natural pedal "feel" through hydraulic reaction
- Pressure in the brake system can be double that of the main hydraulic system
- Full hydraulic flow and pressure are retained for downstream components, except for the small volume required to displace brake cylinder pistons during brake applications

Typical Circuit Schematic





Typical model show. Dimensions may vary slightly between units.

SPECIFICATIONS

Model Number	Maximum Brake Pressure Setting	Flow Capacity	Brake Port
	PSI	GPM	
06-460-522	1850 ± 50	3-24	9/16-18UNF
06-460-658	1850 ± 50	3-24	1/2-20UNF
06-460-660	1150 ± 50	3-24	1/2-20UNF
06-460-666	950 ± 50	3-24	9/16-18UNF
* 06-460-676	1550 ± 50	3-12	9/16-18UNF

* Normally used with disc brakes (no residual check valve)

Consult ZF Off-Highway Solutions Minnesota Inc. Applications Department for other available models.

NOTE: All models have SAE #10 pressure ports, flow through ports and return ports.

PERFORMANCE DATA

System pressure . . . . 0 to 2000 PSI
Master cylinder, bore & stroke . . . . 1.62 in x 1.50 in
Master cylinder, capacity . . . . 3.1 in^3
Push rod travel with power . . . . approximately 0.2 in
Push rod force with power . . . . 340 lb at 1500 PSI brake line pressure
Push rod travel without power . . . . approximately 1.844 in
Push rod force without power . . . . 1500 lb at 725 PSI

Consult ZF Off-Highway Solutions Minnesota Inc. for application detail.
Technical Data for any specific model furnished upon request.

Boosted Dual Master Cylinder

Intended for Brake systems with Brake Assisted Steering

DESCRIPTION

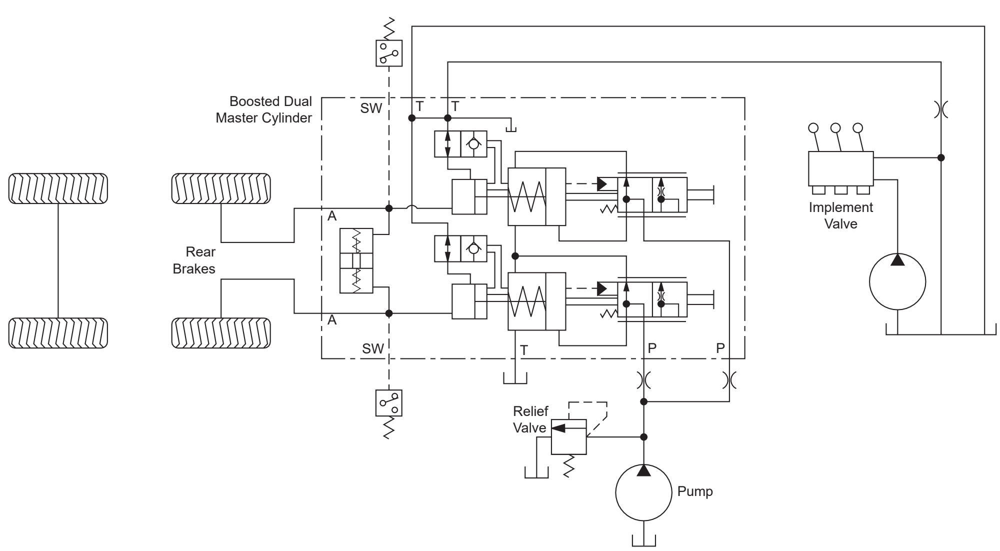
The Boosted Dual Master Cylinder is used to modulate output pressures up to 1500 PSI. This is used in conjunction with properly sized brakes using mineral base oils and booster oil from a standby pressure source such as that of a transmission. This unique integrated design can easily adapt to many dual systems to provide steering assist power braking with one pedal applied or full power braking with both pedals applied giving equally balanced brake pressures.

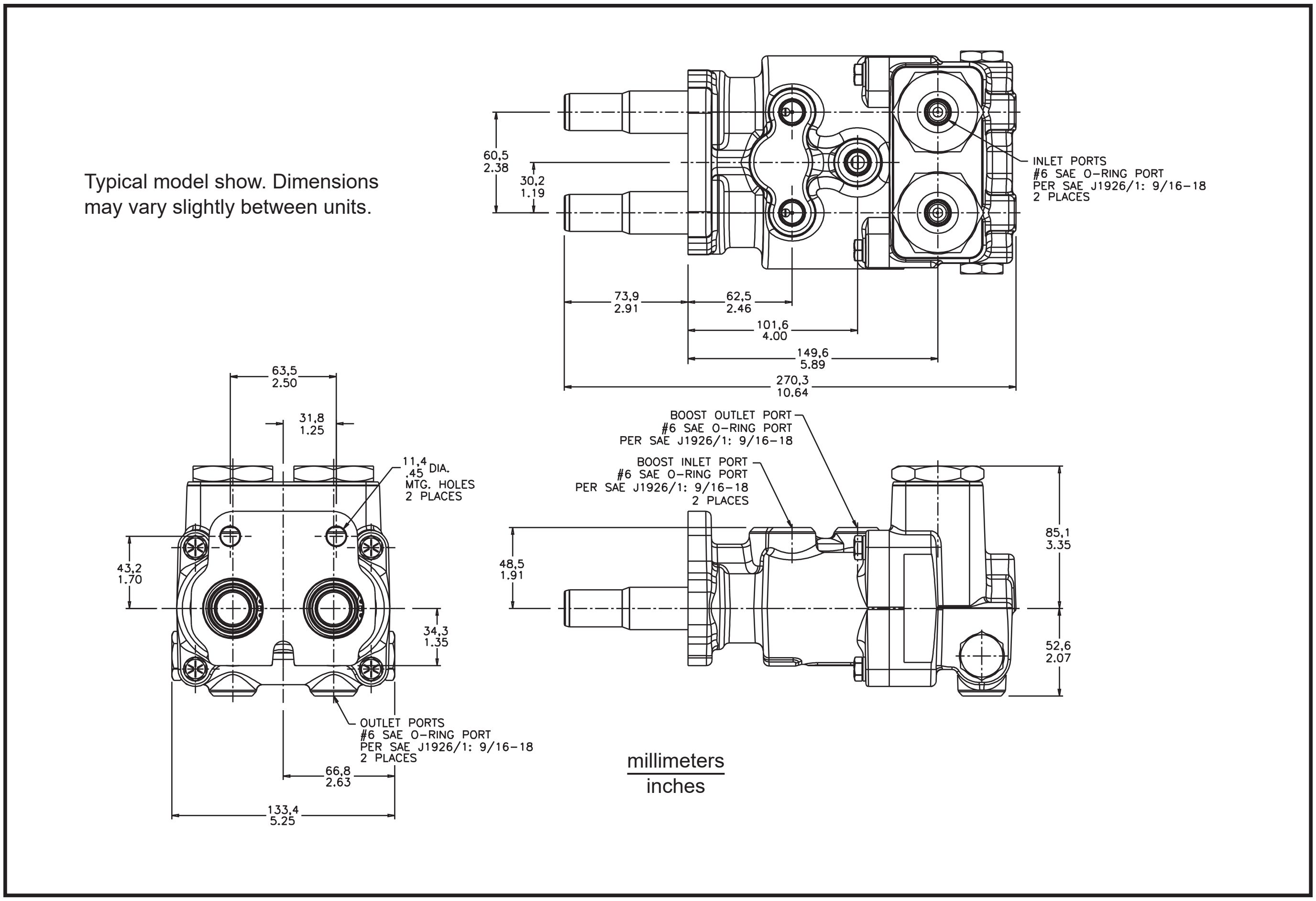
The Boosted Dual Master Cylinder can be used in a number of hydraulic systems where a constant flow of 0.7 to 1.5 GPM can be provided for each side with inlet boost pressures controlled up to 450 PSI.

FEATURES

- Power-off braking through master cylinders
- Open center spool construction provides smooth brake modulation at all pressures
- Direct acting pistons provide pedal feel accurately representing brake pressures
- Balance piston seals fluid loss from one master cylinder side should the opposite side brake line become severed
- Reduced pedal force during steering assist braking
- Compact integrated design for use in restricted spaces
- Internal pressure balancing piston provides allowance for pedal offset
- Master cylinder design promotes bleeding without the use of bleeder screws
- All connections are SAE o-ring boss for leakage integrity
- Master cylinder for use with mineral base oils only

Typical Circuit Schematic





SPECIFICATIONS

Consult ZF Off-Highway Solutions Minnesota Inc. Applications Department for available models.

PERFORMANCE DATA

Booster pressure . . . . to 450 PSI
Brake line pressure . . . . to 1500 PSI
Master cylinder displacement . . . . to 1.1 in^3
Effective booster area . . . . 3.35 in^2
Master cylinder area . . . . 0.99 in^2
Maximum pressure equalization displacement . . . . 0.13 in^3

This master cylinder design is application specific, consult ZF Off-Highway Solutions Minnesota Inc. for details, options, and modifications.

CONVERSION FACTORS

TORQUE

lb·ft	lb·in	daN·m	N·m	kg·m
1	12	0.13556	1.356	0.1382
0.08333	1	0.01130	0.1130	0.01152
7.376	88.51	1	10	1.019
0.7376	8.851	0.1	1	0.102
7.2359	86.80	0.9806	9.806	1

PRESSURE

PSI	MPa	bar	kPa	kg/mm²	kg/cm²
1	0.006895	0.06895	6.895	0.0007031	0.07031
145	1	10	1000	0.102	10.20
14.50	0.1	1	100	0.0102	1.02
0.145	0.001	0.01	1	0.000102	0.0102
1422	9.807	98.07	9807	1	100
14.22	0.09807	0.9807	98.07	0.01	1

1 Atmosphere = 14.7 lb/in²
1 Atmosphere = 29.92 inches of Mercury
1 Atmosphere = 33.96 ft of water
1 inch of Mercury = 0.491 lb/in² = 13.6 inches of water
1 PSI = 2.0416 inches of Mercury at 62 °F

ENEGRY

ft·lb	kgf·m	kW·hr	hp·hr	J
1	0.1383	3.766e-7	5.051e-7	1.356
7.233	1	2.724e-6	3.653e-6	9.806
2655224	367098	1	1.341	3600000
1980000	273745	0.7457	1	2684520
0.7376	0.1020	2.778e-7	3.725e-7	1

1 BTU = British thermal unit = heat required to raise temperature of 1 lb of water 1 °F
1 BTU = 778.17 ft·lb

VELOCITY

m/sec	ft/s	km/hr	MPH	ft/min
1	3.281	3.6	2.237	196.85
0.3048	1	1.097	0.6818	60
0.2778	0.9113	1	0.6214	54.68
0.4470	1.467	1.609	1	88
0.00508	0.01667	0.01829	0.01136	1

LENGTH

cm	in	ft	m	km	mile
1	0.3937	0.03281	0.01	0.00001	0.000006
2.54	1	0.08333	0.0254	0.000024	0.000017
30.48	12	1	0.3048	0.0003	0.000186
100	39.37	3.281	1	0.001	0.000621
100,000	39,370	3281	1000	1	0.6214
160,934	63,360	5280	1609	1.609	1

VOLUME

in³	cm³	L	qt
1	16.39	0.01639	0.01732
0.06102	1	0.001	0.001057
61.02	1000	1	1.057
57.75	946.4	0.9464	1

1 U.S. gallon = 231 in³
1 U.S. gallon = 0.13368 ft³

FLOW

GPM	in³/s	L/min
1	3.850	3.785
0.260	1	0.983
0.264	1.017	1

FORCE

N	lb
1	0.2248
4.4482	1

ACCELERATION

ft/s²	in/s²	m/s²	cm/s²
1	12	0.3048	30.48
0.08333	1	0.0254	2.54
3.281	39.37	1	100
0.03281	3937	0.01	1

AREA

in²	cm²	mm²
1	6.452	645.2
0.1550	1	100
0.001550	0.01	1

POWER

hp	kW	met·hp
1	0.7457	1.014
1.341	1	1.360
0.9863	0.7355	1

1 hp = 550 ft·lb/s
1 hp = 33,000 ft·lb/min
1 hp = 42.44 BTU/min

TEMPERATURE

°F = (°C x 1.8) + 32
°C = (°F - 32) ÷ 1.8

USEFUL FORMULAS

Piston Area (in^2) = π (3.1416) x r^2 (in)

$$\text{Piston Radius (in)} = \sqrt{\frac{\text{Area (in}^2\text{)}}{\pi\ (3.1416)}}$$

Force (lb) = Piston Area (in^2) x Line Pressure (PSI)

$$\text{Piston Area (in}^2\text{)} = \frac{\text{Force (lb)}}{\text{Line Pressure (PSI)}}$$

$$\text{Line Pressure (PSI)} = \frac{\text{Force (lb)}}{\text{Piston Area (in}^2\text{)}}$$

Volume (in^3) = Piston Area (in^2) x Stroke (in)

$$\text{Piston Area (in}^2\text{)} = \frac{\text{Volume (in}^3\text{)}}{\text{Stroke (in)}}$$

$$\text{Stroke (in)} = \frac{\text{Volume (in}^3\text{)}}{\text{Piston Area (in}^2\text{)}}$$

Volume (gallons) = Flow Rate (GPM) x Time (min)

$$\text{Flow Rate (GPM)} = \frac{\text{Volume (gallons)}}{\text{Time (min)}}$$

$$\text{Time (minutes)} = \frac{\text{Volume (gallons)}}{\text{Flow Rate (GPM}}$$

$$\text{Flow Rate (GPM)} = \frac{\text{Pump Displacement (cir}{*}\text{) x Pump RPM}}{231{*}{*}}$$

$$\text{Pump displacement (cir)} = \frac{\text{Flow Rate (GPM) x 231}}{\text{Pump RPM}}$$

$$\text{Pump RPM} = \frac{\text{Flow Rate (GPM) x 231}}{\text{Pump Displacement (cir)}}$$

PTO/Pump RPM = PTO % Engine Speed x Engine RPM

$$\text{PTO \% Engine Speed} = \frac{\text{PTO/Pump RPM}}{\text{Engine RPM}}$$

$$\text{Engine RPM} = \frac{\text{PTO/Pump RPM}}{\text{PTO \% Engine Speed}}$$

$$\text{Horsepower} = \frac{\text{Flow Rate (GPM) x Line Pressure (PSI)}}{\text{1714 x \% Pump Efficiency}}$$

$$\text{Horsepower} = \frac{\text{Torque (lb}\cdot\text{ft) x RPM}}{5252}$$

$$\text{Torque (lb}\cdot\text{ft)} = \frac{\text{Horsepower x 5252}}{\text{RPM}}$$

$$\text{RPM} = \frac{\text{Horsepower x 5252}}{\text{Torque (lb}\cdot\text{ft)}}$$

* **cir = cubic inches per revolution**
** **231 cubic inches = 1 U.S. gallon**

About ZF Friedrichshafen AG

ZF is a global technology company supplying systems for passenger cars, commercial vehicles and industrial technology, enabling the next generation of mobility.

ZF allows vehicles to see, think and act. In the four technology domains of Vehicle Motion Control, Integrated Safety, Automated Driving, and Electric Mobility, ZF offers comprehensive product and software solutions for established vehicle manufacturers. Learn more at ZF.com.

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