ECM ENGINE CONTROL AND MONITORING

Engine Blow-by Meter Model BB400MR

Instruction Manual

1/02 Part Number 400MRA-7

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Introduction

The BB400MR

The BB400MR (Multi-Range) Engine Blow-by Meter is compact, versatile, and rugged instrument for spot and continuous blow-by measurement of spark ignition and diesel engines. The BB400MR is suitable for use in dynamometer cells, in-vehicle, and as a portable tester.

The BB400MR operates on the vortex shedding principle. Vortex shedding flowmeters use ultrasonic transducers and have no moving parts. The most important feature of these meters is that they give accurate volume flowrate readings over a wide range of blow-by temperature, pressure, gas composition, and viscosity. This is a fundamental property of the measurement technology. Other measurement technologies such as orifice-based techniques give large errors (ex. 10% or greater) if not corrected for blow-by temperature, pressure, composition, and viscosity.

Features of the BB400MR include:

- Operates as a volume flowmeter or volume totalizer
- Integrated, easy-to-read display
- Displays in LPM (liters/min), CFM (cubic feet/min), Total Liters, or Total Cubic Ft.
- Wide measurement range[1]: LPM: 4 to 400 liters/min
  CFM: 0.14 to 14.1 ft^3/min
  Liters Total: 1000 liters
  Ft^3 Total: 100 ft^3
- Insensitive to blow-by temperature, pressure, gas composition, and viscosity
- High accuracy in a difficult environment
- Low flow restriction
- Analog output
- Bi-directional RS-232 control (with PC software included)
- Programmable update rate, analog output range, and averaging period
- Can be field-calibrated (with PC software included)
- Integrated dampers and oil separators
- Compact
- Rugged
- 11 to 28 VDC operation

[1] The BB400MR achieves its 4 to 400 LPM (0.14 to 14.1 CFM) measurement range via three ranges of operation: 4 to 150 LPM (0.14 to 5.3 CFM), 11 to 300 LPM (0.39 to 10.6 CFM), 15 to 400 LPM (0.53 to 14.1 CFM). These ranges are set by opening or closing flow bypass ports inside the meter and meter programming (using keypad).

BB400MR Components List

The following items are included with the BB400MR:

Item No.	Description	Part Number
1.	BB400MR Meter	400MRA-1
2.	Mounting Bracket and Hardware	100A-2
3.	Power Cord, 10’	100A-3
4.	AC/DC Adapter	100A-4
5.	AMP connector and terminals for Power Input (same connector as on AC/DC Adapter)	100A-5
6.	PC Software	400MRA-6
7.	Instruction Manual	400MRA-7
8.	5/32” Allen Key for removing and installing bypass port plugs	400MRA-11

The following are available optional components:

9.	Hirose Connector for Power Input (same silver connector as on Power Cord)	100A-8
10.	12VDC Battery Power Clamp-on Adapter, 1.5’	100A-9
11.	Carrying Case	400MRA-10

Important Operation Notes

1. Mount the meter using the supplied bracket or in a similar orientation (see Figure 4 on page 10). This orientation allows condensed materials to drain from the meter and maintain accurate operation.

2. Do not unscrew the two large (~1" diameter) screws on the sides of the meter. These lead to the ultrasonic transducers and their removal may modify the calibration of the meter.

3. Do not try to remove the flow target from the flow passage inside the meter. The flow target's positioning affects the meter's calibration. If material is condensed in the flow passage, a pipe cleaner or a gun barrel brush (with plastic bristles) may be used to clean the passage but avoid running the end of the brush into the flow target.

4. Blow-by is largely exhaust gases, therefore be careful that all plumbing used with the meter is sealed and that the blow-by is safely vented.

5. Route and cable-tie hoses and wires away from hot or moving objects and ignition wires.

How to Use

Blow-by

Blow-by is the gas flowing out of an engine's crankcase. If you take off the oil filler cap when an engine is running, the misty stuff that comes out is blow-by.

Blow-by is primarily caused by the leakage of combustion gases from inside the cylinder into the crankcase via the piston rings. It also comes from gases leaking past the valve guides or turbocharger bearings. Blow-by is mostly exhaust gases with a little oil mixed in.

A blow-by meter quantifies how well an engine's rings, valve guides, and turbocharger bearings (if the engine has a turbo) are sealing. If an engine is worn out, the rings will leak and a lot of combustion gases will leak into the crankcase. What is an acceptable blow-by flowrate depends on the engine's design and its operating condition (temperature, speed, and load).

Blow-by information is valuable for:

- General engine and vehicle testing to ensure that the engine is not excessively worn or damaged. If an engine has excessive blow-by, it is unlikely that other data taken is relevant.
- Engine emissions testing. Blow-by is often recirculated into the intake of the engine and can affect emissions.
- Piston ring testing or development. A good ring set gives low blow-by.
- Lubricant testing or development. If the oil doesn't do its job, the engine will wear out quickly and blow-by will increase *or* in some cases decrease due to excessive ring deposits.
- Engine durability testing. Blow-by is an excellent indicator of engine condition.
- Maintaining a fleet of vehicles. When blow-by exceeds a certain value, it's probably time to rebuild the engine.

Blow-by can be quantified in two ways:

1. The volume flowrate, in liters per minute (LPM), or cubic feet per minute (CFM) coming out of the engine at a given engine speed and load (ex. 1500 rpm and no load, or 3000 rpm and maximum load).
2. The total volume of blow-by (in liters or cubic feet) that comes out of the engine while it executes a driving cycle (ex. FTP cycle).

The BB400MR can perform both volume flowrate and total volume blow-by measurements. Note that it is "volume", not "mass" being measured. Further, the volume flowrate is at the temperature and pressure conditions at the inlet to the meter (i.e ACFM, not SCFM). To get mass flowrate measurements, temperature and pressure transducers need to be installed in the meter (provisions provided) and the ideal gas law is used.

Setting the BB400MR's Flow Measurement Range

The BB400MR has three ranges of operation. These ranges are set by:

1. Opening or closing flow bypass ports inside the meter. *AND*...
2. Programming the meter for the appropriate flow range. Don't forget to do this!

The bypass ports are accessible by removing the inlet (upper) outer and inner tanks from the meter. Figure 1 shows the ports when the meter is viewed from the top. There are four ports and they are opened (or closed) by removing (or inserting) the supplied 5/16"-24 set screws ("plugs") into them. Table 1 shows what ports should be opened and closed for the three ranges of operation of the M400MR. When the plugs are out, they should be stored by screwing them into the side of the meter. All four plugs are the same, but if you store them in the same-numbered location (as the port number) on the side of the meter, it will be easy to determine what ports are open and closed by looking at the side of the meter. Lightly tighten (10 in-lbf) the plugs into the ports or their storage locations.

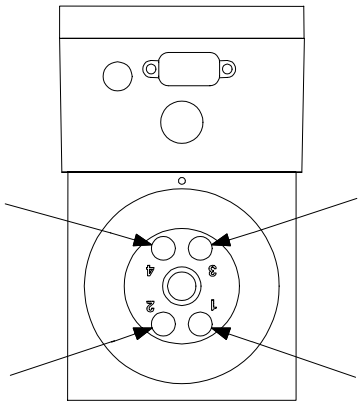

Figure 1: Bypass Ports to Set BB400MR Flow Measurement Range

Range	Bypass Port 1	Bypass Port 2	Bypass Port 3	Bypass Port 4
4 to 150 LPM (0.14 to 5.3 CFM)	CLOSED (PLUG IN)	CLOSED (PLUG IN)	CLOSED (PLUG IN)	CLOSED (PLUG IN)
11 to 300 LPM (0.39 to 10.6 CFM)	OPEN (PLUG OUT)	OPEN (PLUG OUT)	CLOSED (PLUG IN)	CLOSED (PLUG IN)
15 to 400 LPM (0.53 to 14.1 CFM)	OPEN (PLUG OUT)	OPEN (PLUG OUT)	OPEN (PLUG OUT)	OPEN (PLUG OUT)

Table 1: Bypass Ports to Set BB400MR Flow Measurement Range

Always choose the lowest range required for the engine being tested. This way, more flow will go down the center tube of the meter (where the flow is being measured) and the meter will better self-clean.

After changing the meter's measurement range via the bypass plugs, the meter must be programmed for the selected range (see the section **Programming the BB400MR** for more information). If this is not done, the meter will give incorrect flowrate information.

Installing the BB400MR

Figure 2a shows a typical "closed crankcase" PCV (positive crankcase ventilation) system. Note that the blow-by is sucked into the intake manifold of the engine.

Figure 3a shows a typical "open crankcase" road draft system.

Figures 2b and 3b show how the BB400MR is used with each system. Note that the PCV system in Figure 2a is "opened" for the blow-by measurement. If the system is not opened, the measurement will be more a function of throttle position than actual blow-by.

Blow-by is a pulsating flow with some reverse flow (i.e. reversion). The net flow is out of the crankcase, but for a portion of the pulsation expelled blow-by is drawn back into the crankcase. The following conditions accentuate pulsation and reversion:

- Low engine speed.
- Low number of cylinders (i.e. a 4 cylinder engine will have larger flow pulsations than an 8 cylinder engine).
- Small crankcase volume.

The BB400MR is optimized to measure flow in one direction, so to ensure that flow will only pass through the meter in one direction, a damping tank should be placed upstream of the meter. A damping tank of fifteen gallons is sufficient for most engines. There is no problem with using a larger tank but a smaller tank will cause the meter to report a higher flowrate than actual.

The BB400MR has small integral damping tanks and ECM has found that with 10' of ¾" hose separating the engine from the BB400MR, no damping tank was required for a 5.7L V8 engine, even at idle. With a 2L L4 engine, a 15 gallon tank was required (Note: with a 10 gallon tank, there was a 1% error). Since the damping tank is not under any significant pressure or vacuum, it can be made out of plastic.

One simple method for determining the minimum tank volume required is to start with a large damping tank and to remove most of the internal volume by filling the tank almost full of water. Idle the engine and measure the blow-by. Then let 25% of the water out of the tank and measure the blow-by again. If the blow-by decreases then let another 25% out and try again. Stop when the blow-by reaches a minimum value. The volume of the tank not occupied by water is the minimum damping volume required.

In place of a damping tank, a small muffler can be placed inline and upstream of the meter. ECM has found that a lawnmower muffler was equivalent to a 15 gallon tank in the before-mentioned L4 engine case. The backpressure effects of the muffler should be considered. However, in the case of the L4, the backpressure due to the muffler was less than an inch of water. The muffler technique may be preferential for in-vehicle measurements where space for a damping tank is limited.

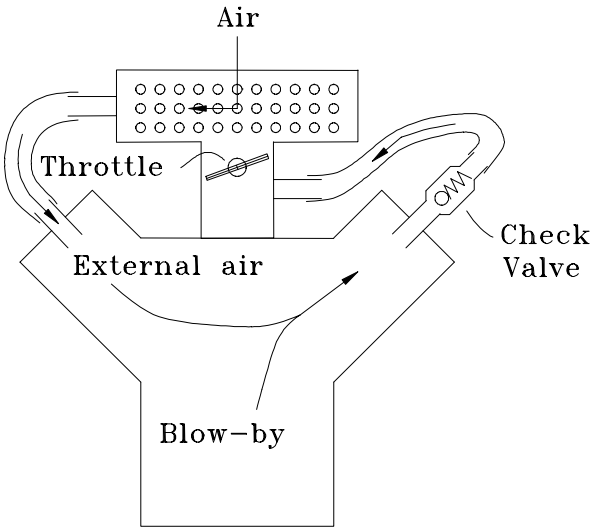

Figure 2a: Closed Crankcase PCV System

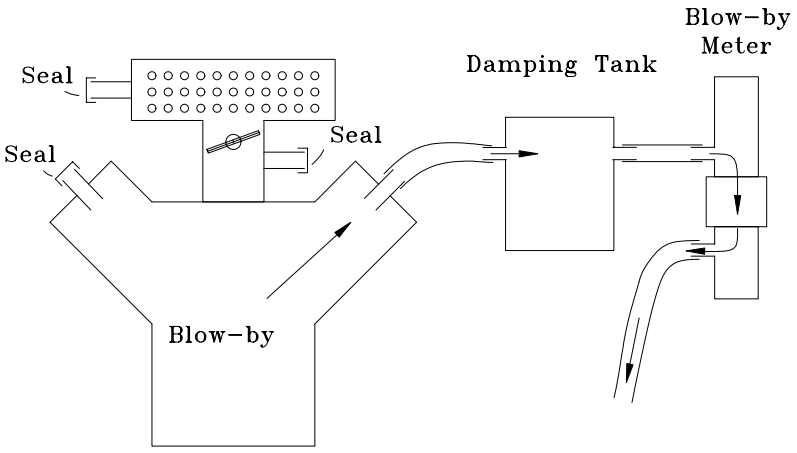

Figure 2b: Using the BB400MR to Measure Engine Blow-by

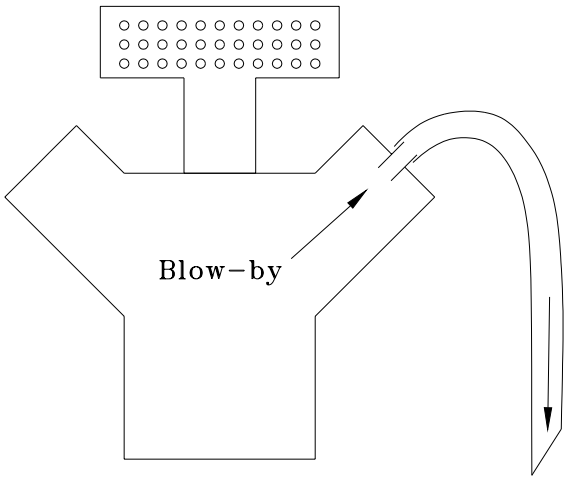

Figure 3a: Open Crankcase Road Draft System

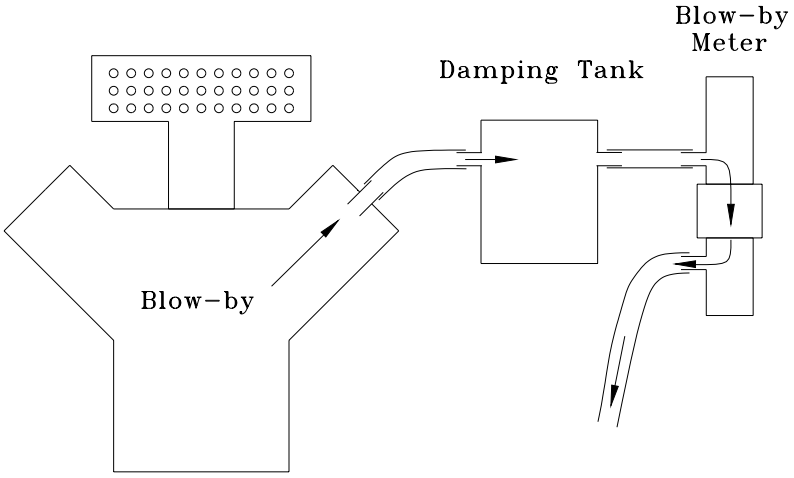

Figure 3b: Using the BB400MR to Measure Engine Blow-by

The recommended procedure to install the BB400MR is as follows:

1. Decide where the BB400MR is to be mounted. The meter should be above the level of oil in the engine and mounted using the supplied bracket. The bracket holds the meter straight up with the top tilted back approximately 30 degrees (see Figure 4). The purpose of this orientation is to drain any condensed material away from the flow-sensing portion of the meter. The meter will work in any position but will work the longest before draining or cleaning is required by mounting it this way.

2. Run a ¾" heater hose from the engine's crankcase (take PCV valve out) to a 15 gallon damping tank and then from the damping tank to the inlet (upper hose connection) of the meter. The hose should not have any "dips" in it where oil and water could collect and plug the hose. Minimize the hose length to minimize the backpressure on the engine.

3. Run a ¾" heater hose from the exit (lower hose connection) of the meter to the outside. Do not vent the blow-by to a room where people are in because blow-by is essentially exhaust (poisonous).

4. The outer tanks of the BB400MR can be installed so that the inlet or outlet point to the left or right. No matter what directions the inlet and outlet face, it is important that the holes in the inner tanks (under the outer tanks) face away from the inlet or outlet hose connections. This maintains the accuracy of the meter's calibration. Use hose clamps on all connections.

5. Pressure and temperature measurements can be made by inserting transducers into the 1/8" NPT pipe taps in the upper tank of the BB400MR.

6. Typically, blow-by is measured with flow from the outlet hose venting to atmosphere. Alternatively, this flow can be throttled (or drawn) slightly so as to maintain a constant engine crankcase pressure (or vacuum) of a few inches of water. The throttling (or vacuum) will have to be adjusted at different engine operating conditions to maintain the constant crankcase pressure (or vacuum); however, the advantage of this technique is that it eliminates any sensitivity to the flow measurement configuration.

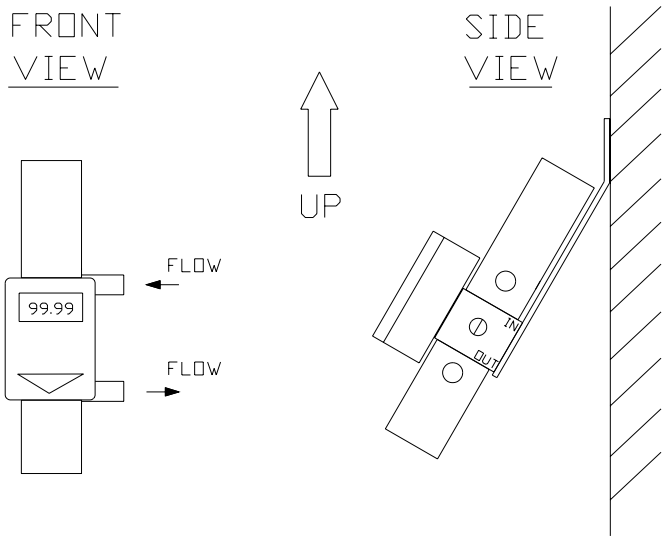

Figure 4: Recommended Mounting Orientation of Blow-by Meter

BB400MR Operation

To operate, the meter requires between 11 and 28 VDC @ 300 mA. The meter can be powered either by the vehicle's battery or the supplied AC/DC power supply.

When the power is attached, the meter will:

- Test the 8-segment displays, then the LEDs.
- Display the serial number (ex. 1234).
- Display the code version (ex. COdE 1.6).
- Display the calibration date (ex. CAL 03.27.2000).
- Display the flow measurement range (ex. rAngE 15 to 400). The measurement range is always given in LPM.
- Display the analog output range (ex. A 0.0 – 5.0).
- Display the volume flowrate range or total volume range corresponding to the analog output range (ex. 0 – 150). The units will be shown on the LEDs.
- During this process, the analog output will be held at 1.000V and then 4.000V. This can be used to check your data acquisition system hook-up to the BB400MR.

(To jump past the above steps, press either the SEL or CLR key).

The meter will then show the operating mode and the flowrate or total flow. The modes are indicated by the 3 LEDs. The available modes are:

1. "Liters per Minute" if the "LPM" LED is on.
2. "Cubic Feet per Minute" if the "CFM" LED is on.
3. "Total Flow in Liters" if the "LPM" and "TOTAL" LEDs are on. Press "CLR" to clear the total flow to zero.
4. "Total Flow in Cubic Feet" if the CFM" and "TOTAL" LEDs are on. Press "CLR" to clear the total flow to zero.

To change the operating mode, press the SEL key.

To zero the total flow, press the CLR key. The modes of the meter can be changed and the meter will still continue adding to the total flow. CLR has no effect on flowrate readings.

The BB400MR has integral damping tanks and oil and water separators on both the inlet (upper) and outlet (lower) sides of the meter. Blow-by can condense in the meter leaving liquid in the tanks. The amount of liquid collected in the tanks over a period in time depends on the engine and the plumbing from the engine to the meter. The lower (or outlet) tank has a transparent sight glass (made of plastic). When liquid begins to fill the sight glass, it is time to drain both tanks. Draining is performed by removing one 1/8" NPT plug from each tank and holding the meter right-side up and then upside down so that all of the liquid drains out of the tanks.

Refer to the **Cleaning the BB400MR** section for more information.

Programming the BB400MR

The BB400MR has four programmable functions. The functions can be programmed either via the meter's keypad or RS-232. The programmable functions are:

1. Display, analog output, and RS-232 update rate. Options are: F: Fast, A: Average, S: Slow. See page 18 for numerical values used to determine update rates.

2. Analog output range. This is the quantity displayed when the meter outputs 5.000 V (for LPM and CFM) or 4.500 V (for Total Liters and Total Cubic Feet). For zero flowrate, the voltage output is 0 V. For zero total flow, the voltage output is 0.5 V.

   For LPM, the options are: 10, 50, 100, 150, 300, 400 (liters/min)
   For CFM, the options are: 0.4, 2.0, 4.0, 6.0, 12.0, 16.0 (ft^3/min)
   For Total Liters, the options are: 10, 100, 250, 500, 1000[1] (liters)
   For Total Cubic Feet, the options are: 0.4, 4.0, 10.0, 20.0, 40.0, 100.0 (cubic feet)

3. Flow averaging period. This is the period over which the meter measures the flow to update the flowrate and total flow. Options are: 0.1s, 0.2s, 0.5s, 1.0s, 2.0s, 5.0s, 8.0s.

4. Flow measurement range. This is the meter's flowrate range of operation set by the bypass ports. The measurement range is always programmed in terms of LPM, even though the meter may be reading in CFM. This function cannot be programmed via RS-232. There are three options:

   150 (for 4 to 150 LPM range). All bypass ports must be closed (i.e. All plugs in).
   300 (for 11 to 300 LPM range). Bypass ports 1 and 2 must be open.
   Bypass ports 3 and 4 must be closed.
   400 (15 to 400 LPM range). All bypass ports must be open (i.e. All plugs out).

When the BB400MR is shipped from ECM, the settings are:

- For display and analog output update rate: A (Average)

- Analog output at 5.0 V for LPM: 400 (liters/min)
  (Note: 0.0 V at 0 liters/min)

[1] The meter's display will show the option of "1000" for Total Liters as "999" while programming. This is because only 3 display segments are left to display the option. So if "999" is selected, the analog output will be at 4.500V when the total flow reaches 1000 liters.

- Analog output at 5.0 V for CFM: 16.0 (ft^3/min)
  (Note: 0.0 V at 0 ft^3/min)

- Analog output at 4.5 V for Total Liters: 1000 (liters)
  (Note: 0.5 V at 0 liters)

- Analog output at 4.5 V for Total Ft^3: 100.0 (ft^3)
  (Note: 0.5 V at 0.0 Ft^3)

- Flow averaging period: 1s.

- Flowrate range of operation: 15 to 400 LPM

To program the functions from meter's keypad, press and release the SEL button until the desired mode is displayed on the LEDs. Then, hold the CLR button down and press SEL three times and the left-hand display will show "1.". "1." refers to programmable function 1 (see previous page): the display and analog output update rate. The currently selected value will be displayed (one of "F", "A", or "S"). To change the programming, press the CLR button. Pressing the SEL button will advance the programming to the "2." function, then the "3." function, and then the "4" function. Pressing the SEL button when at the "4." function brings the meter out of programming mode. As the meter leaves programming mode, it will display what bypass plugs should be in or out (ex. "Put Plug 1.2.3.4. In" or "Pull Plug 1.2. Out", or "Pull Plug 1.2.3.4. Out"). The meter will remember the programming even if its power is turned off.

The BB400MR can also be programmed via the RS-232 port using the supplied software (BB400MR.EXE) or a user-written program that abides by the communication protocol described in the **Serial Port Programming Interface Description** section of this manual.

Analog Output

The analog output range is 0.0 to 5.0 V for flowrate and 0.5 to 4.5 V for total flow.

For total flow, the analog output will start at 0.5 V when zeroed and ramp up to 4.5 V for the total programmed volume. When the total volume exceeds the total programmed volume, the voltage will jump back to 0.5 V and the display will start at zero again. The reason for 0.5 V and 4.5 V (instead of 0 and 5 V) is that data acquisition systems have their poorest accuracy at the extremes of their ranges (ex. 0 and 5 V). The choice of 0.5 and 4.5 V assures that the data acquisition system will be able to accurately detect the beginning and end of the flow total.

For flowrate, the analog output range is 0.0 to 5.0 V. Since the meter will not normally be at either extreme, this range is satisfactory for all data acquisition systems.

BB400MR Serial Communication Software

The BB400MR has a powerful serial communication capability that allows the user to remotely:

- Display the volume flowrate or total flow volume in real-time
- Change the mode of operation (i.e. LPM, CFM, Liters Total, Ft^3 Total)
- Program the meter (except for the "Measurement Range" which only can be programmed using the BB400MR's keypad)
- Calibrate the meter

A DOS PC-compatible program (BB400MR.EXE) is supplied to demonstrate this capability. BB400MR.EXE may be run as a stand-alone DOS program or in a DOS window within Windows 3.1, 95, or 98.

BB400MR.EXE can graphically display the flow rate or total flow in real-time. It is possible to have different operating modes for the BB400MR.EXE display and the meter display. For example, the BB400MR.EXE graph could be displaying Liters Total while the meter is displaying LPM.

BB400MR.EXE is a menu-driven program. The menu structure is shown below:

Menu	**Submenu**	**Function**
FILE	Load Cal File From Disk	Loads a calibration file from the PC disk into BB400MR.EXE.
	Save Cal File to Disk	Saves a calibration file from BB400MR.EXE to the PC disk.
	Process Raw Data File	Loads a raw data file (*.RAW) from the PC disk, creates a final downloadable calibration file (*.BB), and saves the processed calibration file on the PC disk.
	Quit	Exits BB400MR.EXE.
SETUP	Operating Mode	Sets LPM, CFM, Liters Total, or Cubic Feet Total on the BB400MR.
	Display & Analog Output Update Rate	Sets Fast, Average, or Slow update rate for the BB400MR display and analog output.

	Analog Output Range	Sets the flow value which corresponds to the high voltage condition of the analog output on the BB400MR. For LPM and CFM operating modes, this is the value at 5.0 V. For the Liters Total and Cubic ft. Total, this is the value at 4.5 V.
	Flow Averaging Period for	Sets the value of the averaging period flow calculations in the BB400MR. Possible values are 0.1s, 0.2s, 0.5s, 1.0s, 2.0s, 5.0s, and 8.0s.
	PC Comm Port	Sets the PC communications port to either COM1 or COM2.
COMMANDS	Real-Time Flow Display On	Starts real-time text display mode on the PC. Values for all four of the BB400MR operating modes are displayed.
	Real-Time Flow Display Off	Halts real-time text display mode on PC.
	Clear Total Flow Value	Clears the totalizer value in the BB400MR.
	Download Cal File to BB400MR	Downloads a calibration file to the BB400MR. The file must first be loaded into BB400MR.EXE using the FILE menu.
	Upload Cal File from BB400MR	Uploads the current calibration file from the BB400MR.
PLOTS	Real-Time Plot	Starts a real-time plot of one of the flow variables.
	Plot Setup	Sets the real-time plot type (LPM, CFM, etc.) and the plot scales.

The protocol to communicate with the BB400MR is in the **Serial Port Programming Interface Description** section. With the information contained there, software can be written to communicate with the BB400MR via RS-232.

Specifications and Limits

Measurements and Accuracy

Parameter	Range	Accuracy	Repeatability
Liters/min flowrate	4 to 150	1% of reading or 1 LPM whichever is greater	0.5% of reading
Liters/min flowrate	11 to 300	1% of reading or 2 LPM whichever is greater	0.5% of reading
Liters/min flowrate	15 to 400	1% of reading or 3 LPM whichever is greater	0.5% of reading
Ft^3/min flowrate	0.14 to 5.3	1% of reading or 0.04 Ft^3/min whichever is greater	0.5% of reading
Ft^3/min flowrate	0.39 to 10.6	1% of reading or 0.07 Ft^3/min whichever is greater	0.5% of reading
Ft^3/min flowrate	0.53 to 14.1	1% of reading or 0.11 Ft^3/min whichever is greater	0.5% of reading
Liters total flow	0 to 1000	1% of reading	0.5% of reading
Ft^3 total flow	0 to 100.0	1% of reading	0.5% of reading

Flowrates and total flows are for the blow-by temperature and pressure at the inlet to the meter (i.e. ACFM, not SCFM).

Accuracy values shown are for a clean meter.

Pressure drop is 0.5" H_2O at 20% of the maximum flowrate of the selected flow measurement range. For 4 to 150 LPM range, 0.5" H_2O @ 30 LPM. For 11 to 300 LPM range, 0.5" H_2O @ 60 LPM. For 15 to 400 LPM range, 0.5" H_2O @ 80 LPM.

Operational Limits

Blow-by Temperature Range: 0 to 250°C (32 to 482°F).
Electronics Temperature Range: -20 to 85°C (-4 to 185°F).

Output Specifications

Analog Output:

- 0 to 5 V for LPM and CFM volume flowrate
- 0.5 to 4.5 V for Total Liters and Total Ft^3 volume
- Output Impedance: 100 Ohm
- Output Connector: Female BNC, Signal = Center, Ground = Shell

  Note: The analog output ground is internally connected to the power ground.

Display and Analog Output Update Rate Averaging Filters:

Update Rate Selected	Weighting of Current Data	Time Between Updates
"S" Slow	2%	0.80 sec.
"A" Average	5%	0.40 sec.
"F" Fast	12.5%	0.20 sec.

For example, on "F" (Fast), every Flow Averaging Period (programmable from 0.1s, to 8.0s), the flowrate during that period is determined. This flowrate (Q_new) and a previously calculated average flowrate (Qavg_old) are used to calculate a new average flowrate (Qavg_new) according to the weighting formula: Qavg_new = 0.125 x Q_new + (1 - 0.125) x Qavg_old. Qavg_new is applied to the outputs (display, analog output, and RS-232 output) every 0.20 second.

RS-232 Output:

- DB9M connector on BB400MR
- Pin 2 Tx (from BB400MR), Pin 3 Rx (to BB400MR), Pin 5 Ground
- Use "straight-through" cable to PC

Serial Port Programming Interface Description

Background

The BB400MR may be operated under remote control using a standard RS-232 serial port. The interface allows easy integration of the BB400MR into virtually all data acquisition systems. Any operation which is possible with the front panel keys, except for programming the "Flow Measurement Range", may be performed remotely using serial port commands. The flow calibration curve may also be uploaded and downloaded using the interface. For examples of remote control operation, try using the BB400MR.EXE (MS-DOS PC) software included with the BB400MR.

The BB400MR may be operated both under remote control and "local" control at the same time. Setup parameters such as the operating mode may be changed either on the meter or with the serial port interface. The most recent command received by the meter will set the value of the parameter.

Real-time flow data may be uploaded using a poll command. Values for all four of the possible operating modes (LPM, CFM, Liters Total, or Ft^3 Total) are uploaded when a real-time poll command is executed. This allows the operating mode of the meter to be changed on the front panel during remote operation without affecting the flow values received by the data acquisition system.

Serial Port Commands

The external computer may issue commands to the BB400MR only when it is displaying a flow value. The BB400MR will not react to serial port commands during initialization or

when in the setup menu. The serial port parameters are 4800 baud, no parity, 8 data bits, 1 stop bit.

Many of the commands are acknowledged by the BB400MR with a two byte code indicating the success or failure of the command. The two byte positive acknowledgment is <D0> <D0>. The negative (fail) acknowledgment is <D1> <D1>. Some commands are not acknowledged since performance of the requested function may be used as an acknowledgment. For example, the poll command for real-time data is "acknowledged" by the presence or absence of the real-time data.

The BB400MR stores setup and calibration data either as one byte "selections" or as four byte floating point "constants". The four byte floating point constants have the low byte (the least significant byte of the fraction part) first. This is consistent with an Intel PC format. An example of a "selection" is the choice of the operating mode (LPM, CFM, Liters Total, or Ft^3 Total). The "constants" are the meter calibration curve values.

There are five serial port command formats: "Control", "Download Selection", "Download Value", "Upload Selection", and "Upload Value".

Control Commands

A "Control" command to the BB400MR consists of a header and the command number sent twice. A total of 7 bytes must be sent. There is no checksum sent with this type of command. The Control command format is:

<C8> <C8> <C8> <C8> <D9> <command> <command>

For example, command number 2, the poll command (send a packet of flow data to the remote computer), would be sent as:

<C8> <C8> <C8> <C8> <D9> <2> <2>.

The valid Control command numbers and their functions are as follows:

1: Upload status byte. Returns <A2> <A2> if the BB400MR is ready to accept serial port commands.

2: Poll command. This command causes the uploading of a packet of flow data. The data is sent as <C8> <C8> <C8> <C8> <LPM> <CFM> <Liters Total> <Ft^3 Total> <Frequency> <checksum byte 1> <checksum byte 2>. The flow data is uploaded in four byte floating point number format. The packet of data is 26 bytes long. This command is not acknowledged.

3: Clear total flow values. Sets both the Liters Total and the Ft^3 Total values to zero. Equivalent to pressing the "CLR" key on the front panel. This command is acknowledged.

8: Clear BB400MR serial port receive buffer. May be used to recover from serial port data errors. This command is acknowledged.

Download Selection Command

A "Download Selection" command to the BB400MR consists of a header, an index, and the one byte value sent twice. A total of 8 bytes must be sent. There is no checksum sent with

this type of command. Index values are listed below. Any indices not listed below should **never** be changed by the external computer. Values successfully received by the BB400MR are acknowledged by <D0> <D0>. A data error is reported by <D1> <D1>.

The "Download Selection" command format is:

<C8> <C8> <C8> <C8> <DA> <index> <selection> <selection>.

The valid index values and selections are:

Index	**Function**	**Valid Values**
1	Operating Mode	0=LPM, 1=CFM, 2=Liters Total, 3=Ft^3 Total
3	UpdateRate	0=Slow, 1=Average, 2=Fast
4	Analog Output at 5V for LPM	0=10, 1=50, 2=100, 3=150, 4=300, 5=400
5	Analog Output at 5V for CFM	0=0.4, 1=2.0, 2=4.0, 3=6.0, 4=12.0, 5=16.0
6	Analog Output at 4.5V for Liters Total	0=10.0,1=100.0,2=250.0,3=500.0,4=1000.0
7	Analog Output at 4.5V for Ft^3 Total	0=0.4,1=4.0,2=10.0,3=20.0,4=40.0,5=100.0
8	Flow Averaging Period (sec)	0=0.1,1=0.2,2=0.5,3=1.0,4=2.0,5=5.0,6=8.0

Download Value Command

A "Download Value" command to the BB400MR consists of a header, an index, a two byte unsigned integer value and a two-byte checksum. A total of 10 bytes must be sent. The index is considered an array index (to an unsigned integer value) in the BB400MR. Values successfully received by the BB400MR are acknowledged by <D0><D0>. A checksum failure is reported by <D1><D1>.

The "Download Value" command format is:

<C8><C8><C8><C8><DE><index><value><Checksum 1><checksum 2>.

This command is used to download the flow calibration curves. There are three calibration curves corresponding to the three available meter ranges. Each calibration curve consists of flow rate data in LPM at a fixed frequency interval. The curves each contain 51 points starting at 0.0Hz with data values at an interval of 200.0Hz. The last point in each curve is 10000.0Hz. The flow rate data is stored as the LPM value times 100. For example, 100.02 LPM would be downloaded as 10002. The index values in the BB400MR for the three calibration curves are:

Meter Range	Index Values
4 to 150 LPM	0 to 50
11 to 300 LPM	52 to 102
15 to 400 LPM	104 to 154

Upload Selection Command

An "Upload Selection" command to the BB400MR consists of a header and the one-byte index sent twice. A total of 7 bytes must be sent. There is no checksum sent with this type of command. Index values are listed in the "Download Selection" command section. This command is not acknowledged.

The "Upload Selection" command format is:

<C8> <C8> <C8> <C8> <DC> <index> <index>.

In response to this command, the BB400MR uploads the one-byte selection value twice, for a total of two bytes. This allows for error checking since the two bytes must match to be considered valid data.

Upload Value Command

An "Upload Value" command to the BB400MR consists of a header and the one-byte index sent twice. A total of 7 bytes must be sent. This command may be used to upload the flow calibration curve. The calibration data format is given in the "Download Value" command section. This command is not acknowledged.

The "Upload Value" command format is:

<C8> <C8> <C8> <C8> <DF> <index> <index>.

In response to this command, the BB400MR uploads the two-byte unsigned integer value and a two-byte checksum for a total of four bytes.

General Information

Power: 11 to 28 VDC @ 300 mA

Terminal 1: +11 to 28 VDC
Terminals 2 and 3: GND (there must be separate lines to the power source ground for each terminal)
Terminal 4: Case

Power Connector:

Silver connector to mate to BB400MR body: Hirose RM12BPG-4S(07)

Black connector to mate to cable P/N 100A-3:
AMP 206060-1 (plug), AMP 206062-1 (clamp), AMP 66105-4 (sockets, 4 req.)

Fuse: Internal, automatically resetable

Pipe Plug Size (on tanks): 1/8" NPT (4 places)

Flow Range Plug Size (in body of meter): 5/16"-24x1/4" stainless steel set screws requiring 5/32" hex allen wrench

Tank Screw Size: 4-40, 3/8" long (8 places)

Mounting Bracket Screw Size: ¼"-20, 3/4" long (2 places)

Materials Exposed to Blow-by: Anodized aluminum, Stainless steel, Teflon, Viton (O-rings)

Dimensions: 4” x 14.5” x 5.25”
102mm x 368mm x 133mm (W x H x D)

Weight: 5.5 lbs. (2.5 kg)

Maintenance and Troubleshooting

The Sight Glass and Cleaning the BB400MR

When liquid begins to fill the sight glass, one 1/8" NPT plug should be removed from each tank and the meter orientated so that the liquid in each tank can drain out. Occasionally, the BB400MR should be disassembled for inspection and cleaning. Intervals between cleanings depend on the engines being tested and the plumbing from the engine to the meter. To determine the proper cleaning interval, the meter should be operated for 100 hours and then have its outer tanks (2) and inner tanks (2) removed from the main body of the meter. Two screws are used to hold each tank on (8 screws total). The tanks pull off the body. The outer tanks may require a little tug to overcome the friction caused by the sealing O-rings. Do not disassemble the BB400MR any more than this.

When the tanks are off, look down the flow tube and bypass ports going through the body of the meter. The paths should be clear except for a bar crossing the flow tube in the middle of its length and two domed objects coming from each side of the flow tube in the middle of the meter. The bar is the vortex generator (i.e. flow target) and the domed objects are the ultrasonic receiver and transmitter. If there is solid material in the tube or ports, it should be removed. To do this, a pipe cleaner or gun barrel brush (with plastic bristles) and acetone are recommended. Do not run the end of the brush into the flow target or it may be damaged and the calibration of the meter may be affected.

Due to the caustic nature of engine blow-by, some of the anodizing black dye may be removed from the meter. This will not cause a problem since it is just the dye that is removed; the anodizing remains on the meter.

Calibrating the BB400MR

The BB400MR can be field-calibrated using the program BB400MR.EXE and a calibration file. The calibration file for the supplied meter is called ####.BB (where #### is the serial number) and is on the same floppy disk as BB400MR.EXE.

The calibration file is a 156-row ASCII file. The first row is the date in format MM/DD/YYYY; where MM is the month (ex. 01 for January), DD is the day, and YYYY is the year. The subsequent 51 rows contain the flow in LPM for a vortex frequency 0 to 10,000 Hz (in intervals of 200 Hz) for the 4 to 150 LPM range. Then there is a blank line followed by another 51 rows containing the flow in LPM for a vortex frequency 0 to 10,000 Hz (in intervals of 200 Hz) for the 11 to 300 LPM range. Then there is another blank line followed by another 51 rows containing the flow in LPM for a vortex frequency 0 to 10,000 Hz (in intervals of 200 Hz) for the 15 to 400 LPM range. BB400MR.EXE allows calibration files to be uploaded from the meter, downloaded to the meter, and generated from new data.

To perform a calibration:

1. Decide which flow measurement range is going to be calibrated (4 to 150 LPM, 11 to 300 LPM, or 15 to 400 LPM). Recalibrating one range has no influence on the other ranges. To calibrate the meter over its entire 4 to 400 LPM range, three calibrations, one for each range, must be performed.

2. Put the BB400MR in the desired flow measurement range using the bypass plugs and programming (see **Setting the BB400MR's Flow Measurement Range**).

3. Connect the BB400MR to the flow calibration apparatus.

4. Connect the BB400MR to a PC and start the program BB400MR.EXE.

5. Activate the option "REAL-TIME CALIBRATION DISPLAY ON" to display the meter's frequency at various flows.

6. Starting at a flow of about 4 LPM (for the 4 to 150 LPM range) or 11 LPM (for the 11 to 300 LPM range), or 15 LPM (for the 15 to 400 LPM range), record the frequency from the BB400MR and the actual (i.e. not corrected to "standard" conditions) volume flowrate entering the BB400MR (in LPM). Keep in mind that due to pressure and temperature changes between the flow calibration apparatus and the inlet of the BB400MR, the flow entering the BB400MR (Vbb) is related to the flow reported by the flow calibration apparatus (Vfca) according to the relationship:

   $$Vbb = (Pfca/Pbb) \times (Tbb/Tfca) \times Vfca$$

   Where: Pfca and Pbb are the absolute pressures at the flow calibration apparatus and the inlet to the BB400MR respectively.

   Tfca and Tbb are the absolute temperatures (in degrees Kelvin or Rankine) at the flow calibration apparatus and the inlet to the BB400MR respectively.

7. Increase the flow and repeat step 6 (above) in steps until approximately 150 (or 300, or 400) LPM. Up to 51 datapoints can be taken. The first datapoint must be "0.0 0.0" (at zero flow).

8. After the data has been taken, make a copy of the ".raw" data file that came with the meter but use another name for the copy (ex. COP3211.RAW). Enter the copy (ex. COP3211.RAW) using any editor (ex. MS Word). Note that the first row of the file has the month/day/year. Edit the date. The date is followed by the data for the 4 to 150 LPM range of the meter. Then there is a blank line followed by the data for the 11 to 300 LPM range. Then there is another blank line followed by the data for the 15 to 400 LPM range. The flow data consists of lines of: frequency, a single space, and the flowrate. Delete the lines of data for the flowrate range the meter was calibrated at. Type in the data using the format: frequency, a single space, flowrate. The frequency and flowrate must have decimal points. The flowrate must be in LPM and the first datapoint must be "0.0 0.0".

It is important that you only edit the data corresponding to the meter's flow measurement range. If the meter was set-up for 4 to 150 LPM during the calibration, only modify the first data set. If the meter was set-up for 11 to 300 LPM, only modify the second data set. If the meter was set-up for 15 to 400 LPM, only modify the third data set.

The file should look something like this:

```
12/25/1998          ←the date in format: month/day/year
0.0 0.0             ←the first data point in format: frequency LPM (i.e. Vbb)
322.0 4.1           ←the second data point in format: frequency LPM (i.e. Vbb)
  .                   .
  .                   .
  .                   .
9282.0 151.1        ←the last data point in format: frequency LPM (i.e. Vbb)
                    ←blank line.  Following data is for 11 to 300 LPM range
0.0 0.0             ←the first data point in format: frequency LPM (i.e. Vbb)
350.1 11.3          ←the second data point in format: frequency LPM (i.e. Vbb)
  .                   .
  .                   .
  .                   .
9583.0 299.4        ←the last data point in format: frequency LPM (i.e. Vbb)
                    ←blank line.  Following data is for 15 to 400 LPM range
0.0 0.0             ←the first data point in format: frequency LPM (i.e. Vbb)
292.3 16.1          ←the second data point in format: frequency LPM (i.e. Vbb)
  .                   .
  .                   .
  .                   .
9997.5 398.1        ←the last data point in format: frequency LPM (i.e. Vbb)
```

A minimum of two and a maximum of fifty one data points are to be entered for each flowrate range of operation. The last frequency must be less than 10,000.

9. Save the data file. It must have the extension ".raw" (ex COP3211.RAW).

10. Start the program BB400MR.EXE and activate the option "PROCESS RAW DATA" (under "FILE"). The program will ask for the filename of the data file to process. For the above example, COP3211.RAW would be entered. The program will process the file and produce a calibration file with the same filename but the extension .BB (ex. COP3211.BB).

11. Activate the option "LOAD CAL DATA FROM DISK" (under FILE). The program will ask for the filename of the calibration file. For the above example, CAL3211.BB would be entered. To download the calibration file to the BB400MR, use the "DOWNLOAD CAL DATA TO BB400MR" option (under COMMANDS). The calibration file will be downloaded to the BB400MR. Note that the calibration file, not the data file is to be downloaded to the BB400MR.

12. Connect the BB400MR to the flow calibration apparatus again and check its accuracy.

Problems and Solutions

1. Meter display very jumpy and/or indicates zero flowrate intermittently.

   Probable cause #1: Too much liquid has condensed in the meter.

   Solution: Remove one drain plug from each tank and allow the liquid to drain out.

   Probable cause #2: Noisy power or power that drops below 11 V.

   Solution: Ensure that clean power of between 11 and 28 VDC @ 300 mA is applied to the meter. Direct connections to the vehicle's battery are recommended and examine the power using an oscilloscope to see if the voltage drops below 11 V, even for a short time.

1. Meter shows a non-zero flowrate at zero flow (Note: it can of course show a non-zero flow *total* at zero flow).

   Probable cause #1: See Probable cause #2 (above)

   Probable cause #2: Damaged ultrasonic receiver and/or transmitter

   Solution: Contact ECM.

2. Only one segment of the display lights.

   Probable cause: One of the two power grounds has been incorrectly wired.

   Solution: Correctly wire the power to the meter. See **General Information** section.

3. The BB400MR does not power-up with a new power cable.

   Probable cause: One of the two grounds has not been wired.

   Solution: Correctly wire the power to the meter. See **General Information** section.

4. Meter forgets operating mode and programming.

   Probable cause: EE Prom in the meter has expired.

   Solution: Contact ECM.

6. Meter reacts too slowly or is too “jumpy”.

   Probable cause: Meter display and analog output update rate, and flow averaging period are improperly set for application.

   Solution: If meter is too slow, make display and analog output update rate faster, and flow averaging period shorter. If meter is too jumpy, make display and analog output update rate slower, and flow averaging period longer.

   See **Programming the BB400MR** on page 12 for more information.

7. Meter is displaying flow numbers much higher or much lower than it should be.

   Probable cause #1: Meter bypass port set-up and meter flow measurement range programming do not match (ex. all ports closed but meter set-up for 15 to 400 LPM range).

   Solution: Refer to the sections **Setting the BB400MR’s Flow Measurement Range,** and **Programming the BB400MR**.

   Probable cause #2: Meter was improperly field-calibrated.

   Solution: Download factory calibration file to meter (####.BB where #### is the serial number) or repeat field-calibration.

Safety Warnings

In installation and use of this product, comply with the National Electrical Code and any other applicable Federal, State, or local safety codes.

Always wear eye protection when working near engines, vehicles, or machinery.

During installation, turn off the power and take all other necessary precautions to prevent injury, property loss, and equipment damage. Do not apply power until all wiring is completed.

Never work on a running engine.

When installing the BB400MR's on a stopped engine, it is best to think-out your moves before you make them.

Make certain the plumbing does not leak before testing the engine.

Vent the output gases from the BB400MR away from people. The gases are exhaust and poisonous.

Route and cable-tie all hoses and cables away from hot, moving, sharp, high energy (spark), and caustic objects.

Take into consideration the movement of the engine, chassis, and wind buffeting when instrumenting the engine.

Clear tools away from the engine before starting.

Operate the engine only in a well-ventilated area and never when you or one of your co-workers is tired.

When operating the BB400MR in a vehicle, the operator should keep his or her eyes on the road.

One measure of professionalism is how much you and your co-workers can accomplish without an injury. Always be at your professional best. Think and act with safety in mind.

Warranty and Disclaimers

WARRANTY

The products described in this manual, are warranted to be free from defects in material and workmanship for a period of 365 days from the date of shipment to the buyer. Within the 365 day warranty period, we shall at our option repair such items or reimburse the customer the original price of such items which are returned to us with shipping charges prepaid and which are determined by us to be defective. This warranty does not apply to any item that has been subjected to misuse, negligence or accident; or misapplied; or modified; or improperly installed.

This warranty comprises the sole and entire warranty pertaining to the items provided hereunder. Seller makes no other warranty, guarantee, or representation of any kind whatsoever. All other warranties, including but not limited to merchantability and fitness for purpose, whether express, implied, or arising by operation of law, trade usage, or course of dealing are hereby disclaimed.

The warranty is void if the BB400MR is disassembled beyond its four tanks.

LIMITATION OF REMEDY

Seller's liability arising from or in any way connected with the items sold and/or services provided shall be limited exclusively to repair or replacement of the items sold or refund of the purchase price paid by buyer, at seller's sole option. In no event shall seller be liable for any incidental, consequential or special damages of any kind or nature whatsoever, including but not limited to lost profits arising from or in any way connected with items sold and/or services provided to buyer, whether alleged to arise from breach of contract, express or implied warranty, or in tort, including without limitation, negligence, failure to warn or strict liability. In no event shall the company's liability to buyer arising out of or relating to the sale of any product or service exceed the purchase price paid by buyer to the company for such product or service.

PRODUCT CHANGES

We reserve the right to discontinue a particular product or to make technical design changes at any time without notice.

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