BORGWARNER

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Resolver Calibration Process

Version 1.2

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2. Resolver Calibration Process

There are two aspects to resolver calibration. The first one is to calibrate the resolver circuitry within the PM controller (Resolver Delay, **PM Gen 3 Family only**). The other adjusts for any angle offset (Gamma Adjust) between the resolver and the magnetic field of the motor (rotor position). This 2nd process must be done for all of the inverters.

Important Note: It is not necessary for the high-voltage DC to be connected to the inverter. However, spinning the motor will generate a DC voltage in the inverter, even if the inverter is off. This voltage is dangerous, take proper precautions. If a high-voltage DC is connected to the inverter make sure that it is high enough in value that the voltage generated by the motor will be less than this battery voltage.

In addition the Motor Type EEPROM parameter must already be set for the motor that you are using. You can usually find the Motor Type number for the motor in the motor specific manual provided by Cascadia Motion. If you do not know the number for your motor, please contact Cascadia Motion for more information.

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2.1 Resolver Delay (PM Gen 3 Family Only)

The Resolver Delay adjustment provides a calibration of the timing of the reading of the resolver by the analog to digital converter of the Digital Signal Processor (DSP). The goal is to read the peak of the sine/cosine wave coming from the resolver.

For controllers that are using a SIN/COS encoder this section does not apply.

The Resolver Delay is factory preset to a default value. This value will generally be accurate enough for motor operation. Fine tuning the value will maximize the signal coming from the resolver.

Following parameters associated with the Resolver Delay can be accessed by the RMS GUI software and CAN application:

Resolver_PWM_Delay_EEPROM_(Counts)	This parameter is used to program the Resolver Delay into the non-volatile memory of the controller.
Resolver_Delay_Command	This parameter allows active adjustment of the Resolver Delay during the calibration process.
Sin_corr_(V)_x_100	This parameter shows the Sine value of the resolver input. It is a times 100 value between ±1.5V.
Cos_corr_(V)_x_100	This parameter shows the Cosine value of the resolver input. It is a times 100 value between ±1.5V.

The Resolver Delay is a number between 0 and 6250 (when operating at default 12 kHz).

To calibrate the delay use the following procedure:

1. Hook the controller up to a computer so that the RMS GUI can monitor the above parameters.

2. Hook the controller to the resolver of the motor.

3. Using the RMS GUI bring the following three parameters to the watch window:
   (a) Resolver_Delay_Command
   (b) Sin_corr_(V)_x_100
   (c) Cos_corr_(V)_x_100

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4. If needed, set the Resolver_Delay_Command to 1100 (default value).

5. Turn the shaft of the motor slowly by hand to maximize the value of Cos_corr_(V)_x_100. The value is updated by clicking the refresh button on the RMS GUI. Leave the shaft at the position that creates the maximum value. It is not important that the position be extremely accurate, the cogging torque of the motor may not allow the motor to rest at the exact maximum.

6. Now adjust the Resolver_Delay_Command to fill in the table below. Remember to click the Refresh button to update the display.

7. Using this information it is now possible to narrow in on the maximum. Try increments of 100. It is not important to be more accurate than 100 counts.

8. Once a value has been determined it can be programmed into the EEPROM using Resolver_PWM_Delay_EEPROM using the normal EEPROM programming process.

Resolver_Delay_Command	Cos_corr_(V)_x_100
0	
100	
200	
300	
400	
500	
600	
700	
800	
900	
1000	
1100	

2.2 Verify Resolver and Motor Direction

With the Resolver Delay completed (if needed) the operation of the resolver can now be checked. The goal of this section is to verify that the resolver is working correctly. The following parameters associated with the Resolver Direction can be accessed by the RMS GUI software or CAN application[1]:

Parameter Name	GUI Address	CAN Address	Description
Gamma_Resolver_(DEG)_x_10	0x0075	ID 0x0A5 Bytes 0,1	This parameter is the actual electrical angle of the motor in degrees times 10. That is 3600 is 360 degrees and 0 is 0 degrees. The electrical angle of the motor should not be confused with the mechanical angle. The electrical angle reflects the number of poles the motor has. For example, if a motor has 12 poles (6 pole pairs), the resolver will go through 6 rotations electrically for every shaft rotation.
Feedback_Speed_(RPM)	0x0097	ID 0x0A5 Bytes 2,3	This parameter will show the motor shaft speed as calculated from the resolver. The speed will be positive for forward direction rotation and negative for reverse direction rotation.
Voltage_Feedback_Speed_(RPM)	0x00BA	Not Available	This parameter will show the motor shaft speed as calculated from monitoring the back EMF of the motor. The speed will be positive for forward direction rotation and negative for reverse direction rotation.
Sin_corr_(V)_x_100	0x0073	Not Available	This parameter shows the Sine value of the resolver input. It is a times 100 value between ±1.5V. Applies only to PM Gen 3 Family, for PM Gen 5/RM/CM this will read 0.
Cos_corr_(V)_x_100	0x0074	Not Available	This parameter shows the Cosine value of the resolver input. It is a times 100 value between ±1.5V. Applies only to PM Gen 3 Family, for PM Gen 5/RM/CM this will read 0.

As the motor shaft is slowly turned by hand in the **Forward** direction the value of Gamma_Resolver_(DEG)_x_10 will slowly increase. When the value reaches

[1] Please refer to the document, CAN Protocol for information about CAN data and other important details

3600 it will reset back to 0. Verify that when the shaft is turned in the forward direction than the value of Gamma_Resolver_(DEG)_x_10 increases. The values of Sin_corr_(V)_x_100 and Cos_corr_(V)_x_100 should also adjust as if they were running through a circle. Imagine Cos_corr_(V)_x_100 on the x-axis and Sin_corr_(V)_x_100 on the y-axis (for PM Gen 3 family only).

If the value of Gamma_Resolver_(DEG)_x_10 decreases or does not change when turning forward then there is wiring issue with the resolver.

When spinning the motor the Feedback Speed parameter should indicate either a positive number for forward rotation or a negative number for reverse rotation.

The next step is to verify the motor direction as determined by the motor phase connections to the inverter. The only way to do this is to spin the motor from an **external source** at a speed sufficient for the controller to measure the back EMF of the motor. Monitor the Voltage Feedback Speed parameter to determine the direction of rotation as being calculated by the controller.

The direction of rotation as measured by Voltage Feedback Speed must match the direction as determined by the resolver. The magnitude of the Voltage Feedback Speed should match the Feedback Speed. If the magnitudes do not match there could be an error in the setup of the resolver (number of resolver poles does not match the motor type setup).

Note that if the motor speed is not high enough the back EMF will be too small for a proper measurement. Typically a motor speed of about ¼ the base speed of the motor should be enough to get a stable measurement.

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2.3 Resolver Angle Offset Adjustment (Gamma Adjust)

The resolver angle offset setting is the most important part of the resolver calibration process. The motor controller should not be operated in speed mode until the resolver calibration process has been completed.

Following parameters associated with the Gamma Adjust can be accessed by the RMS GUI software or CAN application:

Parameter Name	GUI Address[2]	CAN Address	Description
Gamma_Adjust_EEPROM_(Deg)_x_10	0x011A	152	This parameter adjusts the calibration angle between the resolver and the back EMF of the motor. The parameter is set in degrees times 10.
Gamma_Adjust_(Deg)_x_10	0x0010	12	This parameter allows active adjustment of the Gamma Adjust during the calibration process.
Delta_Resolver_In_Fil_(DEG)_x_10	0x0089	ID 0x0A5 Bytes 6,7	This parameter shows the angle (in degrees times 10) between the back EMF of the motor and the resolver.
All code excluding 652F and beyond: Delta_Resolver_In_Fil_at_1000RPM	0x00DF	NA	Displays Delta_Resolver_In_Fil_(DEG)_x_10 at around 1000 RPM.
652F and beyond: Delta_Resolver_In_Fil_On_Coast	0x00DF	NA	Displays Delta_Resolver_In_Fil_(DEG)_x_10 during motor coast down. (See Appendix)
Feedback_Speed_(RPM)	0x0097	ID 0x0A5 Bytes 2,3	This parameter shows the actual speed of the motor.

The next step is to align the magnetic field of the motor with the resolver. The resolver rotational position on the shaft is not necessarily always in the same

[2] GUI address should not be used as the primary reference to search for the parameter. The primary reference is Parameter Name.

place due to manufacturing tolerances, nor is it always aligned with the magnetic field.

To adjust this angle it is necessary for the motor to be connected to the inverter.

To run this calibration it is necessary to spin the motor at a speed that provides sufficient back EMF for the controller to measure. Generally 1000 rpm is sufficient. However for some motors this speed will be too low. For some motors the speed will be too high. A good rule of thumb would be about ¼ to 1/3 of the no-load base speed of the motor.

The motor must either be spinning from an external mechanism or it can be coasting down. In either case the PWM must be OFF (motor not enabled to run) when perform the calibration readings.

If it is necessary to try and operate the motor to allow it to coast down it is recommended that torque mode be used for control and not speed mode. Speed mode can result in high motor currents in an uncalibrated motor.

The controller is not very sensitive to the exact gamma adjust value when operated at no-load. Run the motor with as little load as possible. Use a small torque command to bring the motor speed up to some value above the calibration speed. Then command the inverter off. As the motor coasts down the values can be read as described below.

The internal voltage sensors in the inverter are used measure the back EMF of the motor and thus determine the alignment. The internal sensors that measure back EMF can only measure the voltage when the motor is NOT enabled. Thus it is necessary to have the motor be disabled when monitoring the back EMF.

Put the following variables into the watch window of the RMS GUI or CAN application:

- Gamma_Adjust_(Deg)_x_10
- Delta_Resolver_In_Fil_(DEG)_x_10
- Feedback_Speed_(RPM)

Click the continuous refresh button so that the values will continuously update.

The Delta_Resolver_In_Fil_(DEG)_x_10 will now display an angle (3600 = 360 degrees). The goal is to get this angle to be 900 (90 degrees) if the motor is running in forward direction or -900 (-90 degrees) if the motor is running in reverse direction. If the resolver is properly connected and the motor is spinning at a sufficient speed the displayed angle should remain relatively constant (less than ± 2 degrees) as the motor is spun. If the value is constantly changing or

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staying at a value near zero degrees then it is likely that the motor phasing is not correct. Try swapping two of the motor leads.

While the motor is spinning in **forward** direction at the selected calibration speed (NOT enabled) record the angle Delta_Resolver_In_Fil_(DEG)_x_10. Next determine the angle represented by Delta_Resolver_In_Fil_(DEG)_x_10. Divide the value by 10 to convert it to degrees. Now determine the amount of adjustment necessary to make Delta_Resolver_In_Fil_(DEG)_x_10 be plus or minus 90 degrees as determined by direction of rotation. Increasing Gamma_Adjust_(Deg)_x_10 will decrease Delta_Resolver_In_Fil_(DEG)_x_10.

Repeat the process until Delta_Resolver_In_Fil_(DEG)_x_10 = 90 degrees (900) for positive rotation, or Delta_Resolver_In_Fil_(DEG)_x_10 = -90 degrees (-900) for negative rotation. The goal would be to adjust the Gamma_Adjust_(Deg)_x_10 parameter until Delta_Resolver_In_Fil_(DEG)_x_10 reads within ± 0.7 degrees. Once this goal is achieved, program the value in Gamma_Adjust_(Deg)_x_10 into its EEPROM equivalent, Gamma_Adjust_EEPROM_(Deg)_x_10 to save it permanently as a calibration parameter.

Gamma_Adjust_(Deg)_x_10 can be either positive or negative as needed.

Example:

1. While spinning the motor at 1000 RPM (when it is NOT enabled), the Delta_Resolver_In_Fil_(DEG)_x_10 parameter reads a value of 828.

2. Convert the value to degrees by dividing by 10. 828 / 10 = 82.8 degrees.

3. To get to 90 degrees we need to change by 90 - 82.8 = 7.2 degrees.

4. The value of Gamma_Adjust_EEPROM_(Deg)_x_10 while running the test was 2.9 degrees. So to increase Delta_Resolver_In_Fil_(DEG)_x_10 we need to decrease Gamma_Adjust_EEPROM_(Deg)_x_10. So we calculate the adjustment as 2.9 degrees - 7.2 degrees = -4.3 degrees.

5. Enter the new value into Gamma_Adjust_(Deg)_x_10 and repeat the process to verify that Delta_Resolver_In_Fil_(DEG)_x_10 now reads 900.

6. Program the new calibration value for Gamma_Adjust_EEPROM_(Deg)_x_10 as -43. Reset the power to the controller. Repeat the test to confirm the change.

Helpful hints:

- If it is not possible to spin the motor from an external source, then it is possible to spin the motor from the controller by guessing at various values of gamma adjust that make the motor spin in the desired direction. Make changes in gamma adjust (large changes like 45 degrees are acceptable). An unloaded should not take much torque to get the motor to spin. Once the motor is spinning allow the speed to increase above the ¼ to 1/3 target and then disable the inverter. Watch delta resolver value while the motor is coasting down.

- If using the method of coasting down after the inverter has been enabled, then it can be quite helpful to record the CAN data be sent by the inverter. It is easier to see the exact value of delta_resolver during the coast down.

- A motor that will not spin with any value of gamma adjust likely means that the resolver direction doesn't match the motor phase direction. Either swap both SIN with both COS or swap two of the motor phases.

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3. Appendix

For firmware 652F and beyond the channel Delta_Resolver_In_Fil_at_1000RPM has been replaced with Delta_Resolver_In_Fil_On_Coast. The speed at which Delta_Resolver_In_Fil_(DEG)_x_10 will be displayed is now a function of the motor poles as compared to a set value of 1000 RPM. For the common Cascadia Motion catalog motors this speed is listed below.

Motor Core / CM Common Name	Delta_Resolver_In_Fil_On_Coast Speed [RPM]
SS250-115-DOM iM-225DX-D, iDM-190DX-D, iM-375DZ-D, iM-375SiC-D, iDM-375SiC-D	1050
SS250-115-SOM iM-225DZ-S	1050
SS410-150-DOM iM-425DZ-D, iM-425SiC-D	525

The coast value is calculated via the motor poles and the common PU frequency in the firmware. The equation is listed below:

Delta_Resolver_In_Fil_On_Coast Speed [RPM] = 10500 / Motor Poles

i.e. For a 10 pole motor like the SS250-115-DOM,

Delta_Resolver_In_Fil_On_Coast Speed [RPM] = 10500/10 = 1050 [RPM]

Revision History

Version	Description of Versions / Changes	Responsible Party	Date
0.1	Initial version	Chris Brune	5/24/2011
0.2	Updated document to calibrate motor in forward direction (+90 degrees) or reverse direction (-90 degrees).	Azam Khan	6/27/2011
0.3	Changed sin_corr/2 and cos_corr/2 to Resolver_SIN_Input_x_100 and Resolver_COS_Input_x_100, respectively.	Azam Khan	12/07/2011
0.4	Added references to CAN Addresses to allow users to perform resolver calibration using CAN.	Azam Khan	1/4/2012
0.5	- Renamed Resolver_SIN_Input_x_100 as Sin_corr_(V)_x_100. - Renamed Resolver_COS_Input_x_100 as Cos_corr_(V)_x_100.	Azam Khan	7/18/2012
0.6	Minor correction of sin/cos parameter description. Clarify explanations of process. Address issues surround 1000 rpm as calibration speed. Add use of Voltage feedback to verify motor direction.	Chris Brune	8/3/2012
0.7	"Resolver Delay" calibration in section 2.1 is an optional procedure.	Azam Khan	8/7/2012
0.8	Added Delta_Resolver_In_Fil_at_1000RPM to section "2.3 Gamma Adjust".	Azam Khan	11/19/2013
0.9	Changed Cos_corr/2 value to Cos_corr_(V)_x_100 in the table in section 2.1	Azam Khan	1/23/2014
1.0	Updates for RM (Gen 4 Control Board) product.	Chris Brune	1/19/2018
1.1	Updates to Cascadia Motion Update to reflect PM Gen 5, CM inverters. Added some hints about calibration. General clarifications.	Chris Brune	3/23/2021
1.2	Added note about new Delta_Resolver_In_Fil_On_Coast	C Tigges | ECO 972	4/2/2024