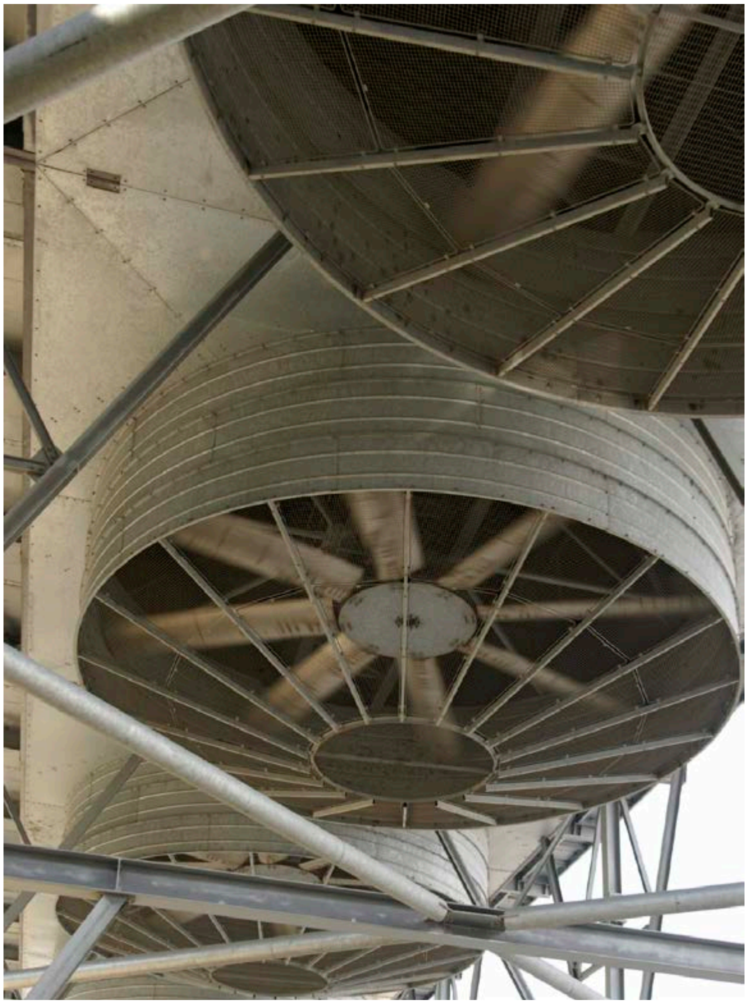

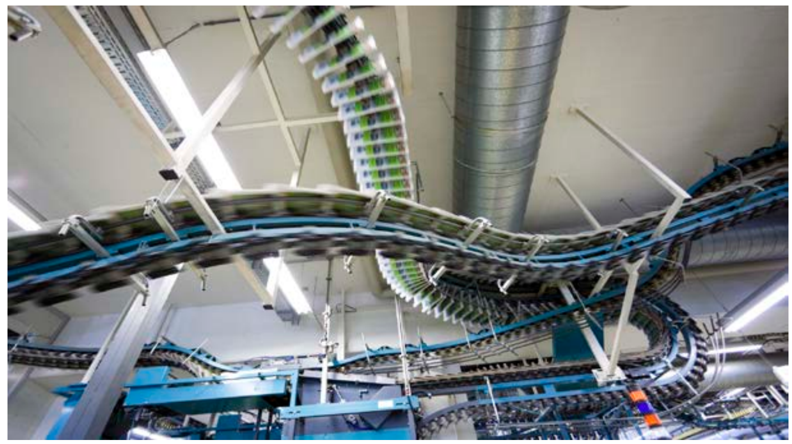

Servo Motor Phasing with Hall Commutation

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White Paper

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The expansion of closed-loop feedback motion control into less traditional applications will undoubtedly bring forth a new generation of specialized low-cost permanent magnet (PM) servo drives. Depending on the complexity of requirements, many of these applications will only require minimal feedback resolution and software flexibility to increase overall efficiency.

Hall sensors are one of the feedback types that may be specifically utilized for the commutation of motor windings at their proper time. It is also the type of device where differential signals *(if available*) could be presented for interpolation to achieve higher feedback resolution and enhance velocity control. However, the push from established industries to utilize more complex technology for higher efficiency and reduced power consumption often presents cost challenges. As a result, drive designers are more likely to eliminate hardware and software that would only be used during the initial commissioning of a servo axis.

One example with Hall commutation may be a software direction Bit: For a positive command, should the motor be defined going in a clockwise *(CW)* or counter-clockwise *(CCW)* direction, relative to some physical reference? Since a software definable direction Bit capability would only be used during initial commissioning, its lack of implementation could be a potential cost saving. In this case, it can be achieved if hardware connections, regardless of the motor and drive manufacturer, are understood to accommodate the physical wiring for the desired direction during the initial documentation and commissioning procedure.

The intent of this white paper is to present a simplified method to determine initial documentation for the proper phasing of a 3-phase PM servo motor with Hall sensor commutation.

There are many different ways to present the wiring connections and have the system work for either physical reference: CW or CCW direction. However, in an effort to minimize complexity, we will focus on only three sets of wiring connections to cover all conditions. They are based on two different physical references and their conversions between each other.

I. Definition of Hall Signals

The Hall-effect or equivalent comcoder feedback signals should be positive and in phase with the positive Bemf voltage of the motor, when the motor's shaft / rotor is rotated in the same direction as the defined phasing sequence ***(referenced in II.a and II.b which are presented on Page 2).*** This means each Hall signal will be positive with its corresponding positive Bemf phase for the same rotational direction of the driven shaft / rotor, when utilized for determining the motor phasing sequence by the motor's manufacturer.

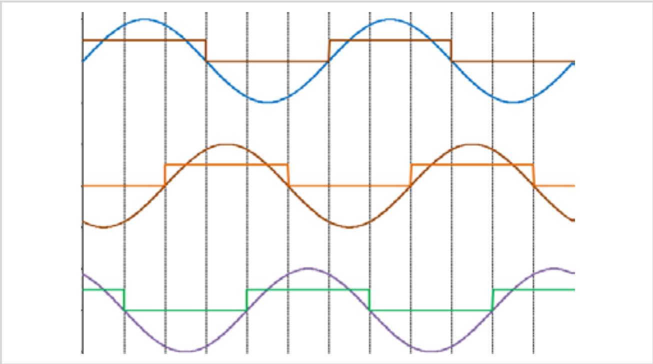


Figure 1: Positive Hall signals in phase shown with each phase of the motor's Bemf for a Wye wound armature, regardless of the chosen convention for commutation sequence (CW or CCW from a single physical reference).

Note: Hall signal nomenclature can easily be misunderstood because of how it is referenced to the direction defining the motor's 3-phase network phasing sequence. For example, assuming we have a motor phasing sequence in the CW direction looking into the torque / mounting endbell for phases U,V and W. Halls then identified as Hu, Hv and Hw could further be described with motor phases as Hu (Hu<u>v</u>), Hv (Hv<u>w</u>) and Hw (Hw<u>u</u>). The underlined letter is the identified motor phase reference when checked with an oscilloscope. In this case, Hall (Hu) identified as Hu<u>v</u> could be verbally expressed as Hu is positive and in phase with the Bemf of motor phase U, and with respect to phase V as the rotor is rotated CW *(where phase U leads phase V by 120 degrees)*. This convention is consistent throughout the white paper. *(Other conventions can be used and applied consistently throughout the procedure.)*

II. Convention for Motor Phasing

a. Most housed rotary servo motors are phased with a positive direction: CW looking into the shaft or mounting endbell *(torque endbell)* of the motor. For this convention we will call the 3-phases: U, V and W. The CW rotation of the shaft *(viewed as looking into the torque endbell)* is therefore defined as phase U leads phase V by 120-degrees, phase V leads phase W by 120-degrees, and so on.

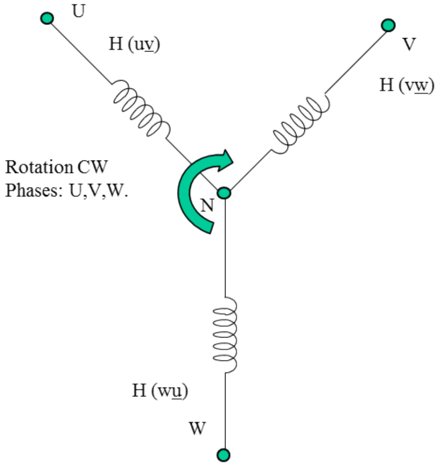


Figure 2a: Looking into the torque endbell (shaft) of the motor

Housed motor viewed looking into the torque endbell

b. Frameless *(unhoused)* rotary servo motors are often phased with a positive direction: CW looking into the lead exit end of the motor. For this convention we will call the 3-phases: A, B and C. The CW rotation of the rotor as viewed looking into the lead exit end is therefore defined as phase A leads phase B by 120-degree, phase B leads phase C by 120-degrees, and so on.

NOTE: The physical reference here *(and NEMA* standard)* is typically opposite of a rotary motor as shown in **II.a above**.

** NEMA stands for National Electrical Manufacturers Association*

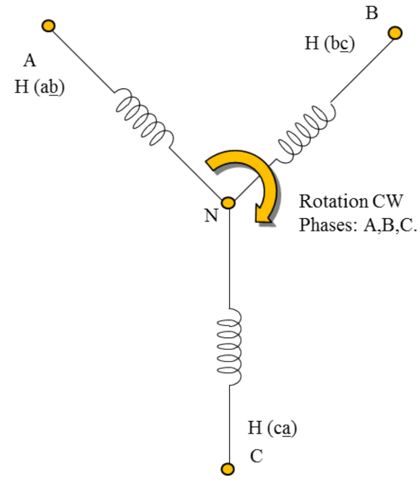
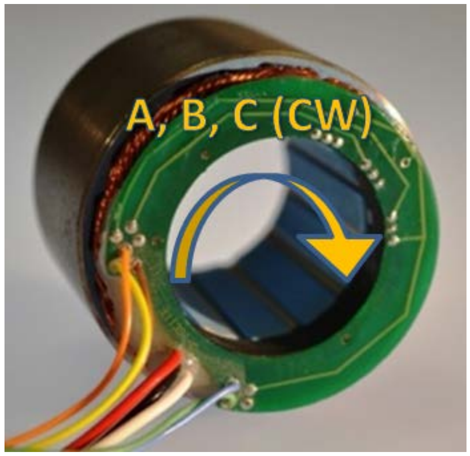


Figure 2b: Looking into the lead exit end of the motor



Frameless motor viewed from the lead exit end

III. Drive Phasing

For the purpose of simplifying this white paper, we will assume the following:

- The servo drive being used has the same connection nomenclature requirements as **II.a on the opposite side** explains.
- The drive expects to see Hall connections per its definition described **under I on Page 2.**
- Motor phasing connections for any positive drive command *(torque, velocity or position)* are per **Figure 2a above**.

IV. Motor Phasing Conditions

Condition I: Motor provided by manufacturer has Bemf phasing and Halls defined per **Figure 2a above**, and user desired positive direction is the same as the motor**:** CW looking into the torque endbell of the motor. *Reminder, this is CCW looking into the lead exit end of the motor.*

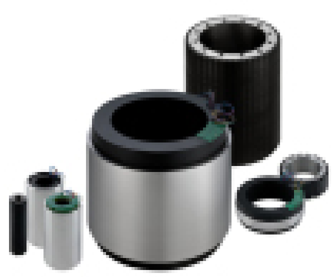
This connection nomenclature would be:

Drive Phase	Motor Phase	Drive Hall	Motor Hall
U to	U	Hu to	H1 or Hu (Huv)
V to	V	Hv to	H2 or Hv (Hvw)
W to	W	Hw to	H3 or Hw (Hwv)

Condition II: Motor provided by manufacturer has Bemf phasing, Halls defined per **Figure 2b on page 3**, and user desired positive direction is the same as the motor**:** CW looking into the lead exit end of the motor. *Reminder, this is CCW looking into the torque endbell of the motor.*

This connection nomenclature would be:

Drive Phase	Motor Phase	Drive Hall	Motor Hall
U to	A	Hu to	H1 or Ha (Hab)
V to	B	Hv to	H2 or Hb (Hbc)
W to	C	Hw to	H3 or Hc (Hca)



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Condition III: Motor provided by manufacturer has Bemf phasing and Halls defined per **Figure 2b on Page 3** *(CW viewed looking into the lead exit end of the motor).* However the user's desired positive direction is the same per **Figure 2a on Page 3** *(CW as viewed looking into the torque endbell of the motor)* and our assumed drive convention.

In this case, the user's reference convention and desired direction of rotation are opposite. It is therefore best to re-label the Hall and motor phase wires / connections to present the subject per **Figure 2b motor on Page 3** (*CW rotation viewed from the lead exit end),* with the same reference convention of **Figure 2a motor on Page 3** (*viewed looking into the torque endbell).* In contrast, the **Figure 3 motor above** is presented with the desired physical reference looking into the torque endbell, but still shown with the opposite direction of rotation.

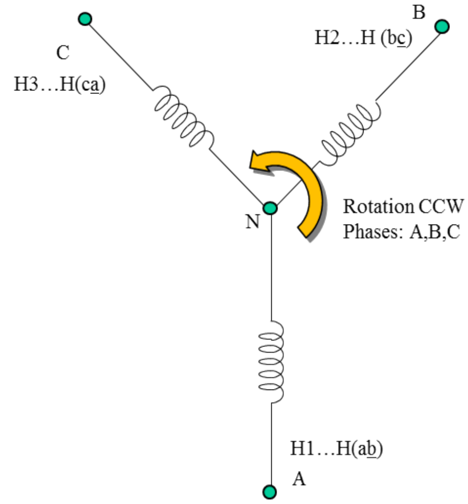


Figure 3: Same as Figure 2b, except looking into the torque endbell of the motor. Appears as a mirror image with 120 degree CW rotation to align center phase: B.

Image above shows two sides of one motor

LEFT: Motor viewed from the lead exit end
RIGHT: Motor viewed from opposite side of the lead

In order to change the direction of rotation, we will first redefine the Hall leads in order to meet the **Definition for Hall Signals noted on Page 2**. Each Hall signal is then positive with its corresponding positive Bemf motor phase when we reverse the manufacturer's presented commutation direction.

We will do this by simply bringing back the Bemf phase reference of each Hall signal, then flip direction by switching **Hall subscripts noted on Page 2.** Next, we substitute Hall subscripts: w for a, v for b, and u for c to match this white paper's convention per **Figure 2a on Page 2.**

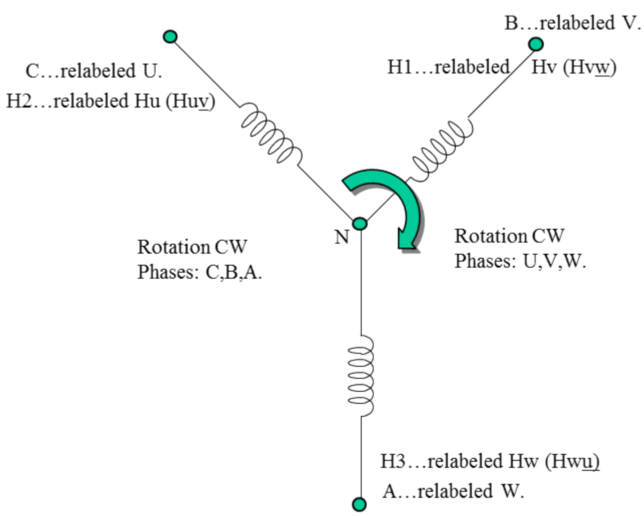
TECHNICAL NOTE: Up to this point, we have flipped or switched the two outside Hall referenced Bemf subscripts and substituted: **w for a, v for b, and u for c**.

Motor Hall	CCW Direction	Flipping Hall Subscripts for CW Direction w/Substitute Identification	Motor Hall Re-Labeled	Drive Hall:
H1 (brown)	Ha (Hab)	Hab becomes Hba or Hvw	Hv or H1 (brown)	Hu
H2 (orange)	Hb (Hbc)	Hbc becomes Hcb or Huv	Hu or H2 (orange)	Hv
H3 (green)	Hc (Hca)	Hca becomes Hac or Hwu	Hw or H3 (green)	Hw

As part of the final step, we can now complete the relabeling of the motor phases: A, B and C. Since we must maintain harmony between our Hall subscript re-labeling convention and the motor phase re-labeling, we must switch motor phase W for A, V for B, and U for C.

Once Hall signal and motor phase re-labeling is complete, we will have the equivalent labeling per **Figure 2a on Page 2** and as shown per **Figure 4 below**.

OBSERVATION: *The advantage of consistently switching the two outside motor phases to change direction is quite simple. Once applied, there is no need to revisit in the future and determine whether you switched the top two phase connections or the bottom two phase connections to change direction.*



Phase: A labeled -> W

Phase: B labeled -> V

Phase: C labeled -> U

Figure 4: Looking into the torque endbell (shaft) of the motor

Final Summary: With the same physical reference, we can now re-arrange our newly labeled U,V and W convention for a CW rotation of the shaft *(viewed from the torque endbell from our A, B and C convention)* for a CCW rotation of the rotor *(viewed from the lead exit end of the motor).* The rotational convention is shown in the table below.

CCW Rotation Viewed from Lead Exit End				`CW Rotation Looking into the Torque Endbell		
Motor Phase	Motor Hall	CCW (A,B,C) Direction		Motor Phase	Motor Hall	CW (U,V,W) Direction
A	H1 (brown)	Ha (Hab)		U [C]	H2 (orange)	Hu (Huv)
B	H2 (orange)	Hb (Hbc)		V [B]	H1 (brown)	Hv (Hvw)
C	H3 (green)	Hc (Hca)		W [A]	H3 (green)	Hw (Hwu)

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Conclusion

Utilizing specialized servo motor controls with minimal feedback and flexible software in less traditional servo applications allows manufacturers to meet many demanding cost requirements. While there are many different ways to connect motors and drives with Hall commutation, regardless of the motor and drive manufacturer, the challenges they present can be resolved by following a powerful, fully-proven and simplified method.

- The white paper explains the detailed process through step-by-step instructions for an in-depth understanding of Hall connections, and the material on rotational (or linear) direction and nomenclature conversion is organized effectively with charts and graphs to minimize complexity. It also presents information on proper wiring for Hall start-up initialization and continuous commutation (with or without feedback interpolation). Armed with this knowledge, engineers and technicians can achieve precise physical wiring connections during the initial documentation and commissioning procedure.
- Summary of Action Steps: If the physical wiring between a 3-phase motor and drive with Hall commutation feedback needs to change, in order to achieve a specific motor direction for a given input command, then one only needs to:

    (1) Flip the two outside motor phase connections *(phase: A and C or U and W)* at the drive.
    (2) Switch the top two associated Hall connections *(Ha and Hb, Hu and Hv)* at the drive per the convention used in this white paper.

ABOUT KOLLMORGEN

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