To: file c:\hagen\wpfiles\bds4.wp6
From: Jon Hagen
Date 8-26-99
Subject: Description of the Kollmorgen Amplifier
Attachments: "Test Limits and Modification" data sheets for compensation cards used with the motors in the Azimuth, Elevation, Tie down, and rotary floor drive systems.
Reference: Kollmorgen manual: description of the BDS4 on page 1-4 and simplified schematic on page F-55.

The BDS4 has three main blocks:

1. Input signal conditioner: analog circuitry whose inputs are the command voltage and the measured velocity and whose output is a torque command voltage V_T. This block implements the BDS4's velocity mode. It does very little when the BDS4 is configured for torque mode.

2. Multiplier: a microprocessor with an A-to-D converter at its input and three D-to-A converters at its output. The input to this block is the torque command voltage V_T and the shaft position θ and the outputs are three current command voltages, V_{I1}, V_{I2}, and V_{I3} which determine the currents, I_1 , I_2 , and I_3 , in the three motor windings. These current command voltages are computed as follows from V_T and θ:

$$V_{I1} = \alpha\, V_T \cos(\theta); \qquad V_{I2} = \alpha V_T \cos(\theta + 120\text{ deg}); \qquad V_{I3} = \alpha V_T \cos(\theta + 240\text{ deg}).$$

3. Power stage: three power amplifiers - one for each of the three motor windings. The current provided by each power amplifier is proportional to the respective current command voltage. Feedback around each power amplifier ensures that the currents exactly match the commanded values. The three currents are therefore given by

$$I_1 = \beta V_T \cos(\theta); \qquad I_2 = \beta V_T \cos(\theta + 120\text{ deg}); \qquad I_3 = \beta V_T \cos(\theta + 240\text{ deg}).$$

The torque provided by the motor is given by

$$\text{Torque} = \gamma\, [\, I_1 \cos(\theta) + I_2 \cos(\theta + 120\text{ deg}) + I_3 \cos(\theta + 240\text{ deg})].$$

Putting the current values, we have

$$\text{Torque} = \gamma\beta V_T\ [\cos^2(\theta) + \cos^2(\theta + 120\text{ deg}) + \cos^2(\theta + 240\text{ deg})] = 3\,\gamma\beta V_T /2\ .$$

Note that the torque is independent of θ; with sinusoidal current control there is no "torque ripple". The power amplifiers are switching circuits that use a 10kHz pulse-width modulation to synthesize the sinusoidal currents. When power is being supplied to the motor, the PWM circuits operate as step-down (buck) converters. When power is being supplied from the motor (regeneration) they operate as a step-up (boost) converters. The transition from buck to boost happens automatically as the amplifier maintains the commanded current.

Kollmorgen rates their motor/amplifier combinations for torque and speed but they give no information about the dynamics of their velocity loop apart from what can be inferred from simplified schematic of the BDS4:

DC Gain
The most basic characteristic of the amplifier is the dc gain. The loop filter does not contain a perfect integrator, as the op amp is bridged with a resistor. At dc, therefore, the gain is finite.

a. velocity mode
When the amplifier is not in Torque Hold mode, the value of the bridging resistor is 10 Megohms. We can calculate the dc gain as follows: The differential voltage at the Command Input is first multiplied by a factor of 0.81 by the differential input amplifier. Referring to the schematic, 16.2k/(10k+10k) = 0.81. Note that this factor, 0.81, may be reduced by adjusting the Command Scale pot. The resulting voltage, 0.81Vdiff, is connected to the summing point of the op amp through a 20k resistor. At dc, the only feedback is provided by the 10M bridging resistor, so the gain of the op amp is 10M/20k = 500 and the gain from the Command Input to the output of the op amp is 0.81·500 = 405. Suppose the motor is stopped and the velocity command is zero. A velocity command of only 20mV will produce 8 volts at the output of the op amp, i.e. full torque.

b. torque mode
In Torque Hold mode, the value of the bridging resistor is 20k so the dc gain is simply .81, the gain of the differential input stage.

Compensation board
The BDS4 has an internal compensation board. Kollmorgen supplies the amplifier with a compensation board tailored for a given motor model. If a different motor is used, the appropriate compensation board must be installed in the amplifier. One might suspect that, to implement a velocity loop, the compensation would also depend on the nature of the load - inertia, friction, bias, etc. Indeed, in addition to the generic compensation board for each motor, Kollmorgen has furnished dozens or hundreds of custom boards. Our tie-down and rotary floor drive systems use generic compensation boards. The elevation and, and azimuth drive systems have compensation boards modified by Vertex. Vertex made two changes to the generic boards. First, they disconnected the velocity feedback by removing R4, R13, and C12. Second, instead of lowering the dc gain by simply grounding the "Torque Hold" input (pin 14 on connector C1) they permanently lowered the dc gain by shunting a 20k resistor across the op amp. They did this by installing a short (jumper) in place of C2, forcing R9 to bridge the op amp. On the B-604A comp card, R9 was already 20k. On the B-606A comp card, they changed R9 from 14k to 20k.