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.

ADMUTH 604 LEMP CARD AS SUPPLIED BY VENDER FOR AE DRIVE (REV) ... Mod THIS sheet orig for Kollmorgen Torque Mode option. ("NOT "TRACH"

ROTARY Prom (REV)

KOLLMORGEN
Industrial Drives

TL BDS4-220H\604A21P
ISSUE 1 SH 1 OF 2
WRITTEN BY T. CONNER 9/1/94
APPROVED BY Tony D. Conner

TEST LIMITS AND MODIFICATION DATA

TEST LIMITS AND

MOTOR DATA :

MODEL	B-604A		MAXIMUM SPEED	2150	RPM
CONT. TORQUE	22.2	LB.FT.	ROTOR INERTIA	0.0015	LB.FT.SEC.^{2}

SPECIAL INSTRUC

AMPLIFIER DATA:

MODEL	220H				
SPEED MONITOR	269	RPM/VOLT	CURRENT MONITOR	5	AMPS RMS/VOLT
CURRENT LIMIT	40	AMPS RMS/PHASE		56.5	AMPS PEAK
MAX SYSTEM SPEED	2150	RPM AT NOMINAL SYSTEM VOLTS			
NOM.SYSTEM VOLTS	230	VAC			

BDS4-R/D

BDS4-COMP1 AMPLIFIER COMPENSATION :

.082 µF

AUX IN	R28	20K	R27	OPEN	C26	OPEN
FILTERS	C22	~~OPEN~~	C33	~~OPEN~~ .022		
R/D TACH SCALING	R24	7.5K	R25	357K		
SPEED SCALING	R23	6.81K				
V.E. SCALING	R6	2K				
CURRENT LIMIT SCALING	R7	OPEN				
VELOCITY LOOP	R4	OPEN	R13	OPEN	C12	OPEN
	R9	20K	R8	OPEN	C2	0 ohms (JUMPER)
	R10	OPEN	C3	OPEN	C1	OPEN

CURRENT LOOP :

R15	562K	C16	2700pf	C14	OPEN
R29	562K	C30	2700pf	C31	OPEN
R32	562K	C35	2700pf	C36	OPEN

MICROPROCCESSOR CODING :

J17	OUT	J18	OUT	J19	IN	J20	OUT

STAMP BDS4-CO

DRIVE-UP OPTION :

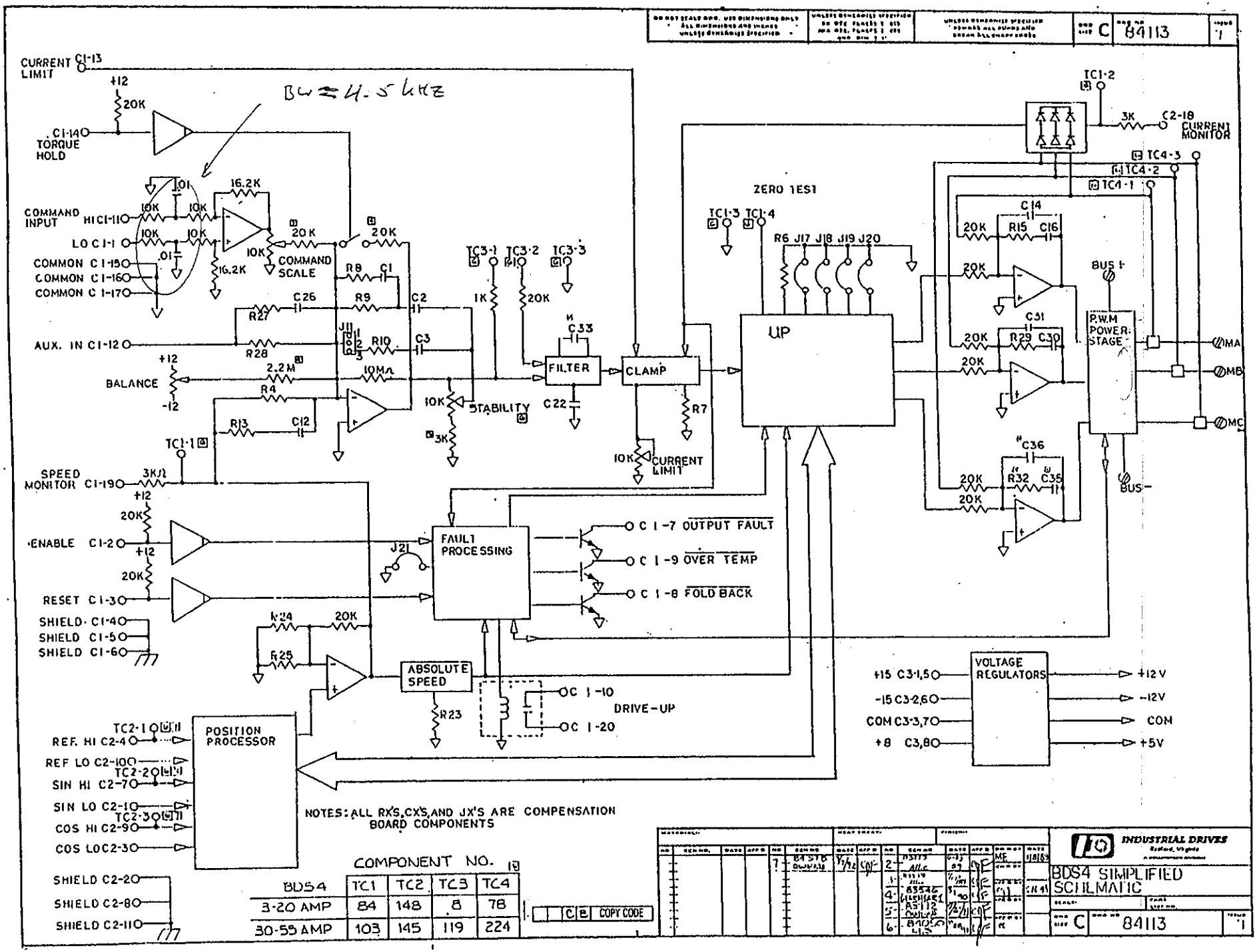
J21	IN

EXAMPLE :

NOTE : J21: IN - GIVES DRIVE-UP WHEN NO FAULTS
J21: OUT - GIVES DRIVE-UP WHEN NO FAULTS AND DRIVE ENABLED

ECN :

25 B = 20K


CURRENT LIMIT C1-13
+12
20K
C1-14 TORQUE HOLD
BW≈4.5kHz
.01
16.2K
COMMAND INPUT HI C1-11
LO C1-1
COMMON C1-15
COMMON C1-16
COMMON C1-17
10K
20K
COMMAND SCALE
R8
C1
C26
R9
C2
R27
AUX. IN C1-12
R28
J11
R10
C3
BALANCE
2.2M
10MΩ
R4
R13
C12
-12
TC1-1
SPEED MONITOR C1-19
3KΩ
ENABLE C1-2
RESET C1-3
SHIELD C1-4
SHIELD C1-5
SHIELD C1-6
TC3-1
TC3-2
TC3-3
1K
C33
FILTER
STABILITY
C22
CLAMP
R7
CURRENT LIMIT
ZERO TEST
TC1-3
TC1-4
R6 J17 J18 J19 J20
UP
TC1-2
3K
C2-18 CURRENT MONITOR
TC4-3
TC4-2
TC4-1
C14
R15
C16
C31
R29
C30
C36
R32
C35
P.W.M POWER STAGE
BUS+
BUS-
MA
MB
MC
J21
FAULT PROCESSING
C1-7 OUTPUT FAULT
C1-9 OVER TEMP
C1-8 FOLD BACK
R24
R25
ABSOLUTE SPEED
R23
C1-10
DRIVE-UP
C1-20
TC2-1
REF. HI C2-4
REF LO C2-10
TC2-2
SIN HI C2-7
SIN LO C2-1
TC2-3
COS HI C2-9
COS LO C2-3
SHIELD C2-2
SHIELD C2-8
SHIELD C2-11
POSITION PROCESSOR
+15 C3-1,5
-15 C3-2,6
COM C3-3,7
+8 C3,8
VOLTAGE REGULATORS
+12V
-12V
COM
+5V
NOTES: ALL RXS, CXS, AND JX'S ARE COMPENSATION BOARD COMPONENTS
COMPONENT NO.
BDS4 | TC1 | TC2 | TC3 | TC4
3-20 AMP | 84 | 148 | 8 | 78
30-55 AMP | 103 | 145 | 119 | 224
COPY CODE
INDUSTRIAL DRIVES
BDS4 SIMPLIFIED SCHEMATIC
C 84113 1

ELEVATION GREGORIAN DRIVE & CARRIAGE HOUSE

~~BASIC~~ COMPENSATION BOARD AS MODIFIED BY VERTEX

KOLLMORGEN
Industrial Drives

TL BDS4-220H/606A2
ISSUE 1 SH 1 OF 2
WRITTEN BY T. CONNER 7/29/93

TEST LIMITS AND MODIFICATION DATA
BDS4-COMP1 FORM REV : B

TEST LIMITS /
BDS4-COMF

MOTOR DATA :

MODEL	B-606A		MAXIMUM SPEED	1550	RPM
CONT. TORQUE	33	LB.FT.	ROTOR INERTIA	0.00224	LB.FT.SEC.²
LOAD INERTIA RANG	0 - .011	LB.FT.SEC.²			

SPECIAL INS

BDS4-R/D

AMPLIFIER DATA:

MODEL	BDS4-220H				
SPEED MONITOR	193.75	RPM/VOLT	CURRENT MONITOR	5	AMPS RMS/VOLT
CURRENT LIMIT	40	AMPS RMS/PHASE		56.56	AMPS PEAK
MAX SYSTEM SPEED	1550	RPM AT NOMINAL SYSTEM VOLTS			
NOM.SYSTEM VOLTS	230	VAC			

ACCEL/DEC
1550

BDS4-COMP1 AMPLIFIER COMPENSATION :

AUX IN	R28	20K	R27	OPEN	C26	OPEN	
FILTERS	C22	.082mf	C33	.022mf			
R/D TACH SCALING	R24	4.87K	R25	357K			
SPEED SCALING	R23	3.65K					
V.E. SCALING	R6	2K					
CURRENT LIMIT SCALING	R7	OPEN					
VELOCITY LOOP	R4	~~22.1K~~ OPEN	R13	~~6.81K~~ OPEN	C12	~~.27mf~~ OPEN	
	R9	20K ~~14K~~	R8	OPEN	C2	~~.15mf~~ SHORT	
	R10	OPEN	C3	OPEN	C1	OPEN	

LOAD INERTI
0.0026
20
50

CURRENT LOOP :

R15	681K	C16	2200pf	C14	OPEN
R29	681K	C30	2200pf	C31	OPEN
R32	681K	C35	2200pf	C36	OPEN

MICROPROCCESSOR CODING :

J17	OUT	J18	OUT	J19	IN	J20	OUT

DRIVE-UP OPTION : J21 IN

NOTE : J21: IN - GIVES DRIVE-UP WHEN NO FAULTS
J21: OUT - GIVES DRIVE-UP WHEN NO FAULTS AND DRIVE ENABLED

ECN :

STAMP BDS-

EXAMPLE :

COPY CODE

TIEDOWN "STOCK" COMP BOARD FOR BG06A UNIT
IN TIEDOWNS

KOLLMORGEN
Industrial Drives

TL BDS4-220H/606A2
ISSUE 1 SH 1 OF 2
WRITTEN BY T. CONNER 7/29/93

TEST LIMITS AND MODIFICATION DATA
BDS4-COMP1 FORM REV : B

TEST LIMITS /
BDS4-COMF

MOTOR DATA :

MODEL	B-606A		MAXIMUM SPEED	1550	RPM
CONT. TORQUE	33	LB.FT.	ROTOR INERTIA	0.00224	LB.FT.SEC.²
LOAD INERTIA RANG	0 - .011	LB.FT.SEC.²			

SPECIAL INS

BDS4-R/D

AMPLIFIER DATA:

MODEL	BDS4-220H				
SPEED MONITOR	193.75	RPM/VOLT	CURRENT MONITOR	5	AMPS RMS/VOLT
CURRENT LIMIT	40	AMPS RMS/PHASE		56.56	AMPS PEAK
MAX SYSTEM SPEED	1550	RPM AT NOMINAL SYSTEM VOLTS			
NOM.SYSTEM VOLTS	230	VAC			

ACCEL/DEC
1550

BDS4-COMP1 AMPLIFIER COMPENSATION :

AUX IN	R28	20K	R27	OPEN	C26	OPEN
FILTERS	C22	.082mf	C33	.022mf		
R/D TACH SCALING	R24	4.87K	R25	357K		
SPEED SCALING	R23	3.65K				
V.E. SCALING	R6	2K				
CURRENT LIMIT SCALING	R7	OPEN				
VELOCITY LOOP	R4	22.1K	R13	6.81K	C12	.27mf
	R9	14K	R8	OPEN	C2	.15mf
	R10	OPEN	C3	OPEN	C1	OPEN

LOAD INERTI
0.0026
20
50

CURRENT LOOP :

R15	681K	C16	2200pf	C14	OPEN
R29	681K	C30	2200pf	C31	OPEN
R32	681K	C35	2200pf	C36	OPEN

MICROPROCCESSOR CODING :

J17	OUT	J18	OUT	J19	IN	J20	OUT

DRIVE-UP OPTION : J21 IN

NOTE : J21: IN - GIVES DRIVE-UP WHEN NO FAULTS
J21: OUT - GIVES DRIVE-UP WHEN NO FAULTS AND DRIVE ENABLED

ECN :

STAMP BDS-

EXAMPLE :

COPY CODE

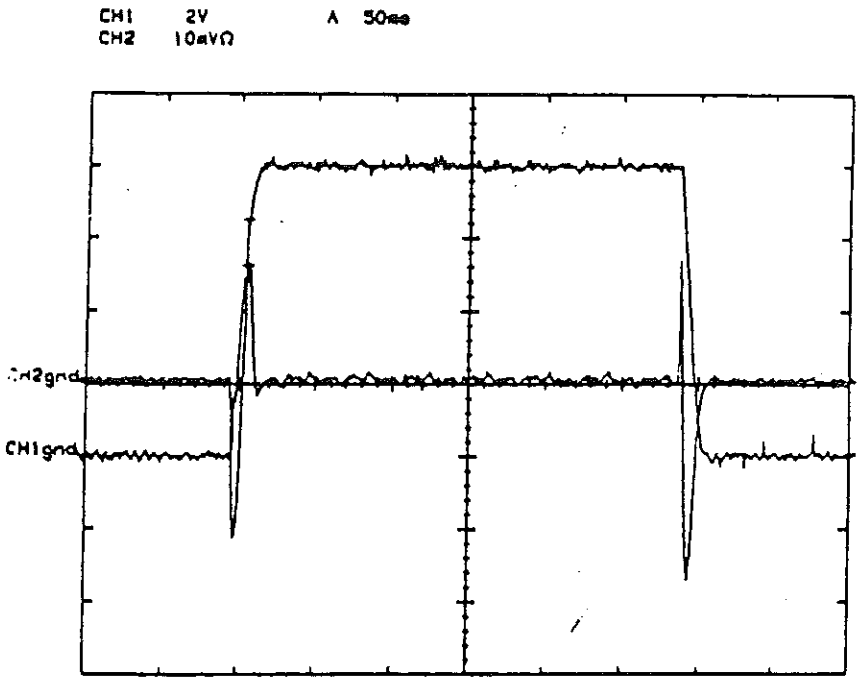
R25 B = 20KΩ

TEST LIMITS AND MODIFICATION DATA

SPECIAL INSTRUCTIONS : CAUTION : SYSTEM MAY BECOME UNSTABLE OUTSIDE SPECIFIED LOAD INERTIA RANGE.

BDS4-R/D 12 BIT SCALED FOR 8000 RPM

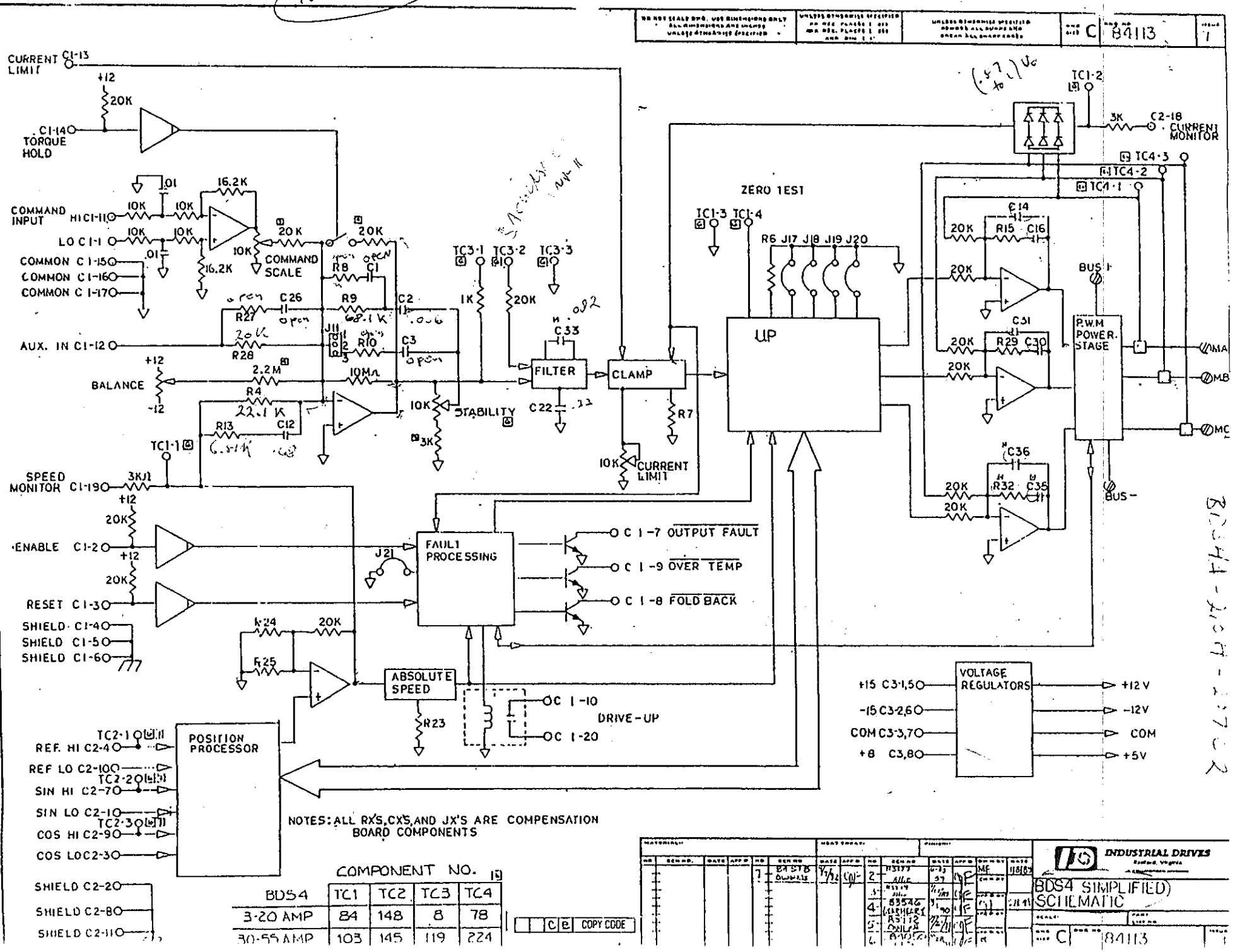
ACCEL/DECEL
1550 RPM



LOAD INERTIA
0.0026 LB.FT.SEC.²
20 A/DIV.
50 MS/DIV.

STAMP BDS-4-COMP1 CARD , in box provided , with amplifier current rating and motor compensation .

EXAMPLE : 220H/606A2-1



NOTES: ALL RX'S, CX'S, AND JX'S ARE COMPENSATION BOARD COMPONENTS

COMPONENT NO.

BDS4	TC1	TC2	TC3	TC4
3-20 AMP	84	148	8	78
30-55 AMP	103	145	119	224

C | B | COPY CODE

INDUSTRIAL DRIVES

BDS4 SIMPLIFIED SCHEMATIC

C 84113

C-84113 Sheet 1 of 1

F-55

KOLLMORGEN
Industrial Drives

TL BDS4-210H\207C2
ISSUE 1 SH 1 OF 2
WRITTEN BY T. CONNER 1/17/96

TEST LIMITS AND MODIFICATION DATA
BDS4-COMP1 FORM REV : B

MOTOR DATA :

MODEL	M-207C		MAXIMUM SPEED	4900	RPM
CONT. TORQUE	4.8	LB.FT.	ROTOR INERTIA	0.0013	LB.FT.SEC.²
LOAD INERTIA RANGE	0 - .00632	LB.FT.SEC.²			

4900 RPM → 8 V

AMPLIFIER DATA:

MODEL	210H				
SPEED MONITOR	612.5	RPM/VOLT	CURRENT MONITOR	2.5	AMPS RMS/VOLT
CURRENT LIMIT	20	AMPS RMS/PHASE		28.28	AMPS PEAK
MAX SYSTEM SPEED	4900	RPM AT NOMINAL SYSTEM VOLTS			
NOM.SYSTEM VOLTS	230	VAC			

BDS4-COMP1 AMPLIFIER COMPENSATION :

AUX IN	R28	20K	R27	OPEN	C26	OPEN
FILTERS	C22	.33mf	C33	.082mf		
D TACH SCALING	R24	31.6K	R25	OPEN		
SPEED SCALING	R23	3.74K				
V.E. SCALING	R6	1.62K				
CURRENT LIMIT SCALING	R7	OPEN				
VELOCITY LOOP	R4	22.1K	R13	6.81K	C12	.68mf
	R9	68.1K	R8	OPEN	C2	.056mf
	R10	OPEN	C3	OPEN	C1	OPEN

CURRENT LOOP :

R15	274K	C16	4700pf	C14	OPEN
R29	274K	C30	4700pf	C31	OPEN
R32	274K	C35	4700pf	C36	OPEN

MICROPROCCESSOR CODING :

J17	OUT	J18	IN	J19	OUT	J20	OUT

DRIVE-UP OPTION : J21 IN

NOTE : J21: IN - GIVES DRIVE-UP WHEN NO FAULTS
J21: OUT - GIVES DRIVE-UP WHEN NO FAULTS AND DRIVE ENABLED

ECN :

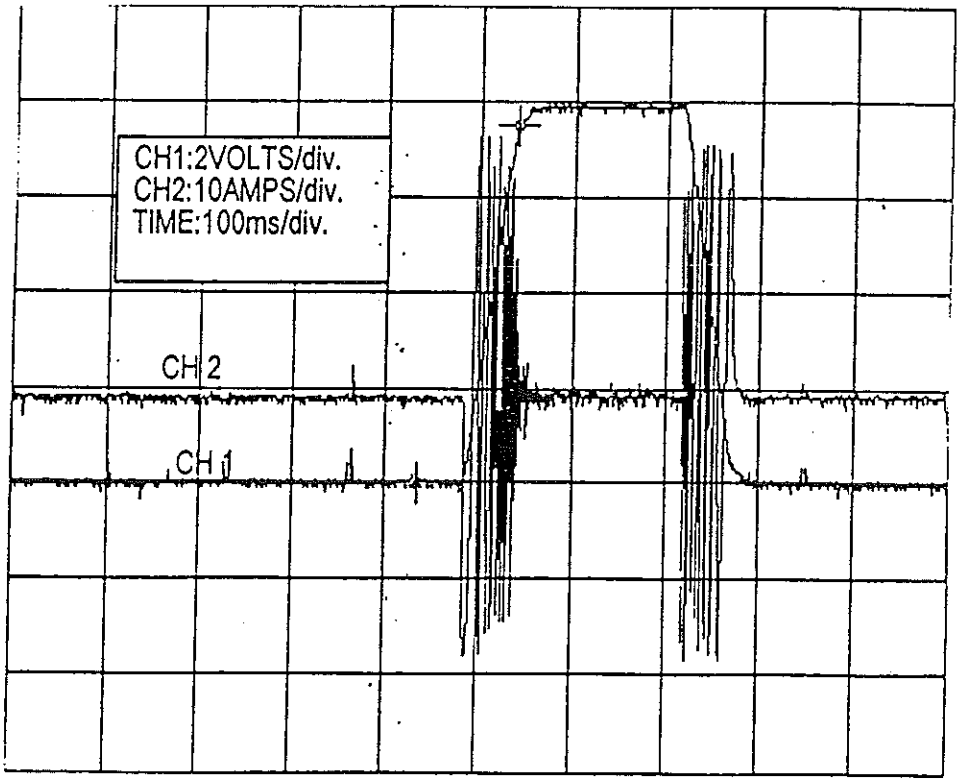
COPY CODE

TEST LIMITS AND MODIFICATION DATA
BDS4-COMP1 FORM REV : B

SPECIAL INSTRUCTIONS : CAUTION : SYSTEM MAY BECOME UNSTABLE OUTSIDE SPECIFIED LOAD INERTIA RANGE.

BDS4-R/D 12 BIT SCALED FOR 4900 RPM

ACCEL/DECEL
4900 RPM



LOAD INERTIA
0.00118 LB.FT.SEC.²
10 A/DIV.
100 MS/DIV.

STAMP BDS-4-COMP1 CARD , in box provided , with amplifier current rating and motor compensation .

EXAMPLE : 210H\207C2-1