PARSONS

Engineering Computation Sheet

Calculations

Electrical

Aluminum Bus Bar Calculation

Titanium Sponge Plant

RTI International Metals, Inc.

Hamilton, Monroe County, MS

Job Number: 444345

Revision	Date	Originator	Checker	Approved
0	7/28/08	Bahram Zamani	HA/JF	Jim Fallon

Aluminum Bus Bar Calculations
Titanium Sponge Plant
Job Number: 444345

1.0 Objective:

Calculate the size of the aluminum bus bar used to supply DC power to Titanium Cells inside Area 300.

2.0 Assumptions:

- The 40 magnesium electrolysis cells require 6VDC for each cell. The bus shall deliver total of 86,000 amperes at 240VDC.
- Aluminum bus bar is chosen for cost saving
- The ambient temperature is 40 deg C at the Mg Recovery Area 300 which is cooled by (16) 30 hp fans incorporated in the walls of the building
- Maximum operating temperature for aluminum bus bar is 90 deg C, recommended by manufacturer.
- If the bus bars be closer than 7-7/8" together then the heat will increase and consequently the resistance of the bus bar and the voltage drop will increase causing problems for the cells.

3.0 Design Basis/Criteria and References:

Calculate the size of the aluminum bus bar used to supply DC power to Titanium Cells inside Area 300. The aluminum bus bar shall sufficiently large to carry 85000 amps thru 240VDC system. The alum. Bus bar should not be over 90deg C.

4.0 Results and Conclusions:

Calculations:

Attachment A: Calculation performed by Abe with Neeltran Co. dated 12/13/07. Results indicate two 8"x32" aluminum bus bars separated 7-7/8" apart at 40 deg C ambient temperature, carrying 85,000 amperes. The bus temperature reaches to 91deg C for normal air convection and 85 deg C for normal air convection together with normal heat radiating from bus.

Attachment B: Calculation performed by Andrew Fynan with Sidehill Copper Works, Inc. dated 11/29/07. Results indicate two 7.87"x 31.5" aluminum bus bars separated 7.87" apart at 40 deg C ambient temperature carrying 86,000 amps. The bus temperature reaches to 83 deg C for normal air convection together with normal heat radiating from bus.

Attachment C: In-house manual calculation. Results indicate two 7.87"x 32" aluminum bus bars separated 7.87" apart, at 40 deg C ambient temperature with 50 deg C rise results in 85,539 amps bus. Also the voltage drop for the entire length of 1250 feet of bus bar is 2.42 Volts on the 240VDC system.

Attachment D: This calculation is for the aluminum bus bar in the rectiformer area. Two 5"x 20" aluminum bus bars separated 5" apart at 40 deg C ambient with 50 deg rise results in 44,915 amps for one rectiformer bus bar.

Results

Parsons choose two 7-7/8 " x 32" aluminum bus bars separated 7-7/8" apart, based on ampere and heat dissipation from two manufacturer's calculations.

ATTACHMENT A SH1

Parallel Rectangular Bus Bar Design

Rev: 12/13/2007

	Losses in Watts	Bus Temp. °C for convection only	Bus Temp. °C convection & radiation
Single Water Cooled BUSSBAR @ desired temperature	725708	91	
Natural convection total bus	362839	91	85
Radiated heat loss, W	16766		
Nominal Current in A	85000	0	Hz
AC Current Phase Angel in degrees: (positive for current lagging voltage, negative for leading)	0	Enter 1 for single phase and 3 for three phase	1
Nominal Voltage in Volts	240		
BUS Ambient Temp. in °C	40	Desired Bus °C	91
ENTER EVEN NUMBER OF EQUALLY SPACED BUS BARS HERE:			2
Fan Factor (1 for natural convection, higher for forced air)			1
Estimated airflow on busbars, Linear Foot per minute			229

BUS MATERIAL, CU or AL	AL
Total BUS Inductance in µH	596.00
Individual bar resistance at desired bus temperature in µΩ	100.44
Current carrying skin thickness in inch (two sides)	8.00
Total Bus resitance, µΩ per linear foot	0.033
Volt-drop at nominal current per foot	0.0028

= Aluminum

ℓ is the length of buss bars

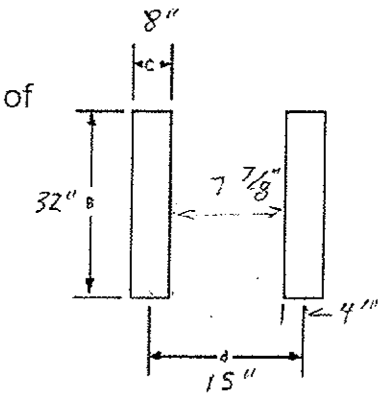
B, in/cm	C, in/cm	d, in/cm	ℓ, in/cm
32.000	8.000	15.748	18000.000
81.280	20.320	40.000	45720.000

CU temp coeff	0.00393
AL temp coeff	0.00430
CU density, lb/in³	0.321
AL density, lb/in³	0.098

ξ 1/ deg K

Total Weight of Bus, lb	451584

1 Pair(s) of Equally-spaced Busbars as:



ALUM BUS BAR CALC BY NEELTRAN

Zamani, Bahram

From: ABE [abe@neeltran.com]
Sent: Thursday, December 13, 2007 9:46 AM
To: Zamani, Bahram
Cc: dmaguire@rtiintl.com; Tony
Subject: re: Bus Bar sizing
Attachments: Bus Bar Thermal 121307 natural 40C.pdf

Hi Bahram,

Per your request, I have attached estimated thermal for the 8"x32" Aluminum busbar with and without the effect of radiation. I assumed only natural convection with no fan air blowing. In reality, the fans will make a substantial reduction on temperature rise. Even with no fan, the temperature rise looks acceptable when I sutracted the radiated heat losses.

Hope this data helps you finalize your design.

Regards,
Abe

> On Tuesday, December 11, 2007 12:00 PM, ABE wrote:
>
> **Date:** Tue, 11 Dec 2007 12:00:11 -0500
> **From:** ABE
> **To:** "Zamani, Bahram"
> **Subject:** re: Bus Bar sizing
>
> *** Attachment omitted: BUS BAR THERMAL 121107 FAN 50C.PDF
> *** Attachment omitted: BUS BAR THERMAL 121107 NATURAL 40C.PDF
> *** Attachment omitted: BUS BAR THERMAL 121107 NATURAL 50C.PDF

Hi Bahram,

I ran my Busbar design program for your busbar under three conditions:

1. Naturally convected at 40 deg C ambient (narrowly unacceptable at 94 deg C)
2. Naturally convected at 50 deg C ambient (unacceptable at 107 deg C)
3. Forced convected at 50 deg C ambient (acceptable at 77 deg C)

Please note to air speed data as an estimate for fan air flow requirements. In forced fan air flow, air speed is by the fan. In natural convection, air speed is a function of the temperature difference of the busbar and ambient. Please also note to the margin of error as there are other physical factors that may influence the simulation results.

Regards,
Abe

> On Monday, December 10, 2007 1:42 PM, Zamani, Bahram wrote:

ATTACHMENT B SH 1

Sidehill Copper Co.

Sidehill Copper Works, Inc.
Preliminary Conductor Sizing

PROPRIETARY

Date	November 30, 2007
Customer	Parsons

mm	inches
200	7.874
800	31.496

Operating Current	I1	86000	(amps)
Number of bars	n	2	
thickness of bars	t	7.874	(in) ✓
width of bars	h	31.496	(in) ✓
gap between bars	g	7.874	(in) ✓
Atmospheric pressure	p	1	(atmospheres)
conductivity	z	59	(% IACS)
Ambient temp deg C	t1	50	(deg C)
operating temp deg C	t2	83	(deg C)
Ambient temp deg K	T1	323.15	(deg K)
operating Temp deg K	T2	356.15	(deg K)
Temp rise deg C	Dt	33	
alpha	a	0.004	
Total cross section	Aa	496.00	(sq in)
current density		173.39	(amps/sq in)

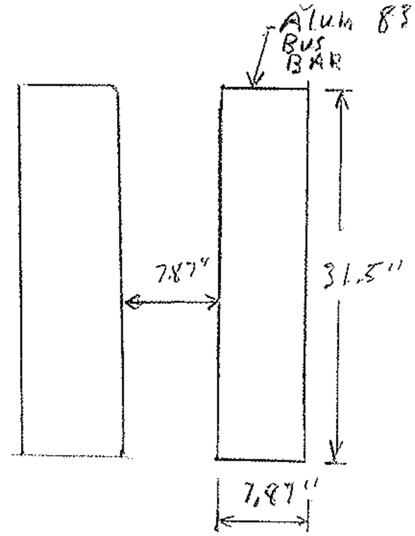
gap emmisivity	ei =	0.9	
bar emmisivity	eo =	0.5	
current rating at Top	I2	87557.267	(amps)
		583.29	lb. per ft.

Area convective inner	Aci	755.90	(sq in / ft)
Area convective outer	Aco	1133.86	(sq in / Ft)
Area radiative inner	Ari	188.98	(sq in / ft)
Area Radiative outer	Aro	1133.86	(sq in / ft)

resist. @ 20 deg C	R20	2.784E-08	(ohms / ft)
resist. @ Top	Rt	3.485E-08	(ohms / ft)
current rating at Top	I2	87557	(amps) ←

Convect. Loss WcAc =	126.18718	(WATTS /FT)
Radiative Loss WrAr =	140.99059	(WATTS /FT)
Power Loss at T op =	267.17776	(WATTS /FT)
Voltage drop at T op=	0.0031067	(VOLTS/FT)

Alum 83°C, 87K Amp



Zamani, Bahram

From: Andrew Fynan [afynan@sidehillcopper.com]
Sent: Thursday, November 29, 2007 11:57 AM
To: Zamani, Bahram
Subject: Re: Bus Bar design

Bahram

There aren't very many places left casting heavy high conductivity aluminum sections so I don't know if 7" x 30" size is still cast.

2 bars 7" x 30" for 86,000 amps estimated 41 deg C rise @ .004 V /Ft

The closest I can come from my metal source is a little bigger

2 bars 200mm x 800mm AA1370 (7.87" x 31.50") 33 deg C rise .003 V/ft (not bad)

If there is field temp rise and voltage drop data from the prior installation that would be usefull as the above values are estimates in free air.

Do you have drawing M-019 ? That looks like it would show the flexibles between the bus and the anodes - are they in the bus scope?

I'm assuming anode is upper furnace connection - is this correct?

Lower connection to furnace- is this a rigid bus connection or is it also flexible?

It looks like the bus could be mostly shop fabricated - making upper bus of one cell to lower bus overall length around

When you have a moment please call.

Best Regards,

Andrew Fynan
Sidehill Copper Works, Inc.
12 Port Access Rd.
Erie, PA 16507
www.sidehillcopper.com
afynan@sidehillcopper.com

> ----- Original Message -----
> **From:** Zamani, Bahram
> **To:** afynan@sidehillcopper.com
> **Sent:** Thursday, November 29, 2007 11:51 AM
> **Subject:** Bus Bar design
>
> Hi Andrew,
> Attached please see the partial floor plan of new design and the typical incoming cell bus bar arrangement details. Please be informed that the details has been copied from the old plan documents and have to be modified for the new design. As you may seen (2) 7" X 30" BARS WITH 19" spacing in between have been used for 60 similar cells with total of 3747line ft.I wonder if we can go with same since in the new plan we only 40 cells with 1500 line ft, please advise.

ATTACHMENT B SH 3

Zamani, Bahram

From: Andrew Fynan [afynan@sidehillcopper.com]
Sent: Friday, November 30, 2007 11:56 AM
To: Zamani, Bahram
Subject: Re: Buss Bar sizing
Attachments: PARSONS PRELIMINARY SIZING Sidehill.pdf

Please see attached
Best Regards,

Andrew Fynan
Sidehill Copper Works, Inc.
12 Port Access Rd.
Erie, PA 16507
www.sidehillcopper.com
afynan@sidehillcopper.com

----- Original Message -----
From: Zamani, Bahram
To: afynan@sidehillcopper.com
Sent: Friday, November 30, 2007 10:17 AM
Subject: Buss Bar sizing

Hi Andrew,
Attached please find "out going cell bus bar detail shown on drawing M-45" and also drawing M-19. Please give a call if any question.

ATTACH. "C"

PARSONS Calculation Sheet	Job Number	WBS Number	Page Number	Sheet 1 of 5
	443821	—	5	

Rev	Date	By	Ck	Title
A	2/25/08	BZ	AH	DC BUS BAR CALCULATION RTI TITANIUM Project

$$I_{(AMP)} = \frac{A^{0.5} \times P^{0.39} \times \theta^{0.61}}{\left[(1+\alpha\theta)\rho\right]^{0.5}} \times (1.02)$$

A = CROSS-SECTION AREA, mm^2

P = PERIMETER OF CONDUCTOR, mm

θ = TEMPERATURE DIFFERENCE BETWEEN CONDUCTOR AND AMBIENT TEMP., C°

α = RESISTANCE TEMPERATURE COEFFICIENT OF ALUMINUM AT AMBINT TEMP. PER C°

ρ = RESISTIVITY OF ALUMINUM, $\mu\Omega cm$

GIVEN:

BAR ⇒ $7\frac{7}{8}'' \times 32''$

$1'' = 25.4$ mm

BAR ⇒ 200.025 mm × 812.8 mm

$A = 200.025 \times 812.8 = 162580\ mm^2$

$P = (200.025 + 812.8) \times 2 = 2025.65$ mm

$\alpha = 0.004\ C^\circ$

$\theta = 90^\circ C - 40^\circ C = 50^\circ C$

$\rho = 2.8\ \mu\Omega\ cm$ (FOR ALUMINUM AA 1350)

ATTACH C

PARSONS Calculation Sheet	Job Number	WBS Number	Page Number	Sheet 2 of 5

Rev	Date	By	Ck	Title
A	2/25/08			DC BUS BAR CALCULATIONS RTI Titanium Project

$$I_{(Amp)} = \frac{\left[(162580)^{0.5} \times (2025.65)^{0.39} \times 50^{0.61}\right] \times 1.02}{\left[(1+0.004\times 50)(2.8)\right]^{0.5}}$$

$$I = \frac{87109.5}{1.833} = 47,522 \text{ AMP}$$

TOTAL RATING = I x (LAMINATIONS MULTIPLYING FACTOR)

= I x 1.8 (FOR 2 BARS)

= **85,539.8 AMP** ←

Reference

AA 1350

Category	Aluminum Alloy
Class	Wrought

Composition

Element	Weight %
Al	99.50 (min)

Mechanical Properties

Properties		Conditions T (°C)	Conditions Treatment
Density (×1000 kg/m^3)	2.6-2.8	25	
Poisson's Ratio	0.33	25	
Elastic Modulus (GPa)	70-80	25	
Tensile Strength (Mpa)	97	25	H12 more
Yield Strength (Mpa)	83		
Elongation (%)			
Reduction in Area (%)			
Shear Strength (MPa)	62	25	H12 more
Fatigue Strength (MPa)	48	25	H19

Thermal Properties

Properties		Conditions T (°C)	Conditions Treatment
Thermal Conductivity (W/m-K)	230	25	All Hlx more

SH 4 of 5

Electric Properties

Properties		Conditions	
		T (°C)	Treatment
Electric Resistivity ($10^{-9}\Omega$-m)	28	25	Hlx more

ATTACH 'C'

PARSONS Calculation Sheet	Job Number	WBS Number	Page Number	Sheet of
				5 of 5

Rev	Date	By	Ck	Title
A	2-27-08	BZ	HA	DC BUS BAR VOLTAG DROP CALCULATION 240VDC BUS

$$R = \rho \frac{L}{A \times 2} \text{ (2 BARS)}$$

L = LENGH OF THE BAR cm
R = RESISTANCE Ω cm
A = CROSS-SECTION AREA cm^2
ρ = RESISTIVITY OF ALUMINUM Ω cm

$L = 1250 \text{ ft} \times 30.48 \text{ cm/ft} = 38100 \text{ cm}$

$A = (32'' \times 25.4 \text{ cm}) \times (7.875'' \times 25.4 \text{ cm}) = 1626 \text{ cm}^2$

$$R = 2.8 \times 10^{-6} \times \frac{38100 \text{ cm}}{2 \times 1626 \text{ cm}^2} = 2.82 \times 10^{-5} \ \Omega$$

$V = R\,I$

$= 2.82 \times 10^{-5} \times 86000$ Ampere $= 2.42$ V_{drop} OR 0.019 V PER ft

ATTACH D

PARSONS Calculation Sheet	Job Number	WBS Number	Page Number	Sheet of
				1 of 1

Rev	Date	By	Ck	Title
A	2/27/08	BZ	HA	DC BUS BAR CALCULATION 5" x 20" ⇒ 127mm x 508mm

$$I = \frac{A^{0.5} \times P^{0.039} \times \theta^{0.61}}{\left[(1+\alpha\theta)\rho\right]^{0.5}} \times (1.02)$$

$$A = (5'' \times 25.4) \times (20'' \times 25.4) = 127mm \times 508mm$$

$$P = \left[(5'' \times 25.4) + (20'' \times 25.4)\right] \times 2 = 1270$$

$$I = \frac{(64516)^{0.5} \times (1270)^{0.039} \times (50)^{0.61}}{\left[(1 + 0.004 \times 50) \times 2.8\right]^{0.5}} \times 1.02$$

$$= \frac{45739}{1.833} = 24953 \text{ AMP}$$

$$I_{TOTAL} = (1.8) \times 24953 = 44915 \text{ AMP}$$

meets the required 43,000 A for each Rectiformer