Fermilab

TM-1372
2230.000

DESCRIPTION OF A HIGH CURRENT WATER COOLED BUS

A. T. Visser

December 1985

December,1985
Ser.#TM-1372
Cat.2230.000
A. T. Visser

Description of a High Current Water Cooled Bus

Contents

1. General

This note describes the construction of a 2000A to 5000A DC water cooled bus constructed from commercially available catalogue components. This design was first used at Argonne National Lab in 1967. The experimental areas use several thousand feet of this bus. This report concludes that bus current densities of about $1000A/_{inch^2}$ are the most economical to use.

2. Construction

The DC bus consists of double extra strong copper pipe, which can be purchased in 20' lengths. A high impact PVC pipe is slipped over the copper pipe for insulation. The copper pipes are joined (brazed) together with straight couplings, 45° elbows or 90° elbows. These joints are then insulated with shrink on sleeves. The copper pipe with the PVC pipe over it can be bent with a pipe bender to make offsets and bends up to 90°. Cooling water flows through the pipe to remove the heat losses. The bus assembly is mounted to structural supports with unistrut clamps fitted around a short length of PVC support pipe. The support pipe has an I.D. slightly larger than the O.D. of the PVC insulating pipe. This allows for movement due to temperature changes. Fig. 1 shows a typical bus section. Short cable jumpers are mostly used to connect the bus to the load. These cables can be connected to special flags which are brazed on to the bus or to a clamped on bus terminal as shown in drawing 6004-ED-76812. The clamped on bus terminal is very handy when the load location changes during the course of an experiment.

The following is a material list of the 5000A bus as used in the experimental areas.

Item	Description	Manufacturer	'85 Price
Copper Pipe	High Conductivity(Alloy 102) Double extra strong Nom. 1-1/2",Hard O.D.-1.9" I.D.-1.1" 20 ft.long,7.24 lbs/ft.	Phelps Dodge	$1.33 per lb.
Coupling	Straight Cat.#5515	Flagg	$18 each
Coupling elbow	45° Cat.#5504	Flagg	$27 each
Coupling elbow	90° Cat.#5501	Flagg	$29 each
End Plug	Home made machined to pipe I.D. with Water Fitting		
Insulating pipe	High impact PVC pipe Nom. 2 inch,Sch.40 O.D. 2.375 inch I.D. 2.067 inch Cat.# 20 ft.long	Carlon	$0.40/ft.
Support Pipe	High impact PVC pipe Nom. 2-1/2 inch,Sch.40 O.D. 2.875 inch I.D. 2.469 inch Cat.#20 ft.long	Carlon	$0.60/ft.
Shrink on Insulation	I.D. min. - 1-1/4 inch I.D. max. - 3 inch Cat.#,SST-30-24, 2 ft.long	Sigma	$19/2ft.
Brazing material	Sil Fos		

Watercooled bus is compact and saves building space, but may not be economical to install below 2000ADC, compared to cables. We have found that the bus can be rather easily dismantled and reused in another place.

We have never been able to reliably use watercooled power cable because of inevitable water leaks within a few years after installation. These leaks are generally caused by the high (~200psi) operating pressures of the cooling water in the Experimental Areas.

3. Selection of an Economical Copper Cross Section for the Bus Conducter

The maximum permissable voltage drop across the bus determines the minimum acceptable copper cross section. A power supply must be able to supply enough voltage to drive the bus and the load at the required current. Bus voltage drop however is often not a problem and the conductor cross section should initially be chosen by weighing the installation cost against the operating cost. A very light bus has high losses and is therefore expensive to run, but costs less to install. The smallest acceptable, from a voltage drop point of view, cross section may not be the best choice.

We have to find out whether a heavy ($1000A/inch^2$) or light ($5000A/inch^2$) bus is preferred from a cost point of view. The following will help to answer this question.

Consider these two cases:

	CASE 1	CASE 2	UNIT
Bus life expectancy	5	10	Years
Average operation current	3000	3000	AMP
Use factor	80	50	%
Bus cross section	S	S	$inch^2$
Bus material cost including misc.	2	2	$/lbs. of Cu
Bus installation cost in experimental area, average difficulty.	2	2	$/lbs. of Cu
Bus weight	3.85S	3.85S	lbs./ft.
Installed bus cost	15.4S	15.4S	$/ft.
Bus resistance at $50^{\circ}C$	$\frac{9.4 \times 10^{-6}}{S}$	$\frac{9.4 \times 10^{-6}}{S}$	Ω/ft.
Bus losses at 3000A	$\frac{84.6}{S}$	$\frac{84.6}{S}$	Watt/ft.
Cost of bus losses including their removal	0.07	0.08	$/KWhr.
Annual cost of bus loss	$\frac{41.5}{S}$	$\frac{29.6}{S}$	$/ft.

Annual bus depreciation	3.08S	1.54S	\$/ft.
Most economical cross section	3.6	4.4	$inch^2$
Most economical current density	833	682	$A/inch^2$

The most economical cross section can be estimated from the total annual bus operating and depreciation cost C, which is a function of the cross section S.

For Case 1:

$$C = \frac{41.5}{S} + 3.08S$$

This cost is minimum for $\frac{dC}{dS} = 0$

$$\text{or} \quad -41.5S^{-2} + 3.08 = 0$$

$$S = 3.6 \text{ inch}^2$$

We can similarly determine that $S = 4.4$ $inch^2$ for CASE 2. The result is interesting. It indicates that current densities in the order of 700 to 1000$A/inch^2$ are probably the most economical in the long run. Most aircooled installations run at these current densities. We have chosen a cross section $S = 1.88$ $inch^2$ and operate mostly at current densities from 1000 to 1600$A/inch^2$. High current densities do not seem to be economical except for short lived or very lightly used installations. The argument that a light bus is the best (cheapest) is generally not true.

4. Bus Parameters

We can list the following parameters for the chosen copper cross section.

Double extra strong copper pipe	Alloy 102, Non-certified
Nominal size	1-1/2"
O.D.	1.9"
I.D.	1.1"
Cross section	1.88 $inch^2$
Weight	7238 lbs./1000'
Installed cost, labor & material (per polarity, 1984)	$30,000/1000'
Resistance at 50°C	$5x10^{-3}\Omega$/1000'
Inductance at 4" center to center, in free air	100μH/1000'
3000A voltage drop	15V/1000'
3000A losses	45KW/1000'
3000A current density	1600A/$inch^2$
Max. water inlet temp.	40°C
Water outlet temp	60°C
Required cooling with water $\Delta T=20^{\circ}C$, 3000ADC	7.2 GPM/1000'
Pressure drop at 7.2 GPM	18 PSI/1000'
Loss of cooling (overtemp) protection, Klixon	80°C
Short circuit stress at 50,000A, 4" center to center	340 lbs./ft.
Thermal expansion at $\Delta T=10^{\circ}C$ average	2 inch/1000'

Comments

The short circuit stresses can be calculated from:

$$F = \frac{5.4I^2 \times 10^{-7}}{d} \text{ lbs/ft.}$$

d = distance between conductor centers in inches

It is estimated that a power supply can deliver 50,000A of short circuit current. Adequate bus supports need to be used.

The required cooling water is calculated from:

$$GPM = \frac{KW \times 3.2}{\Delta T(^{o}C)}$$

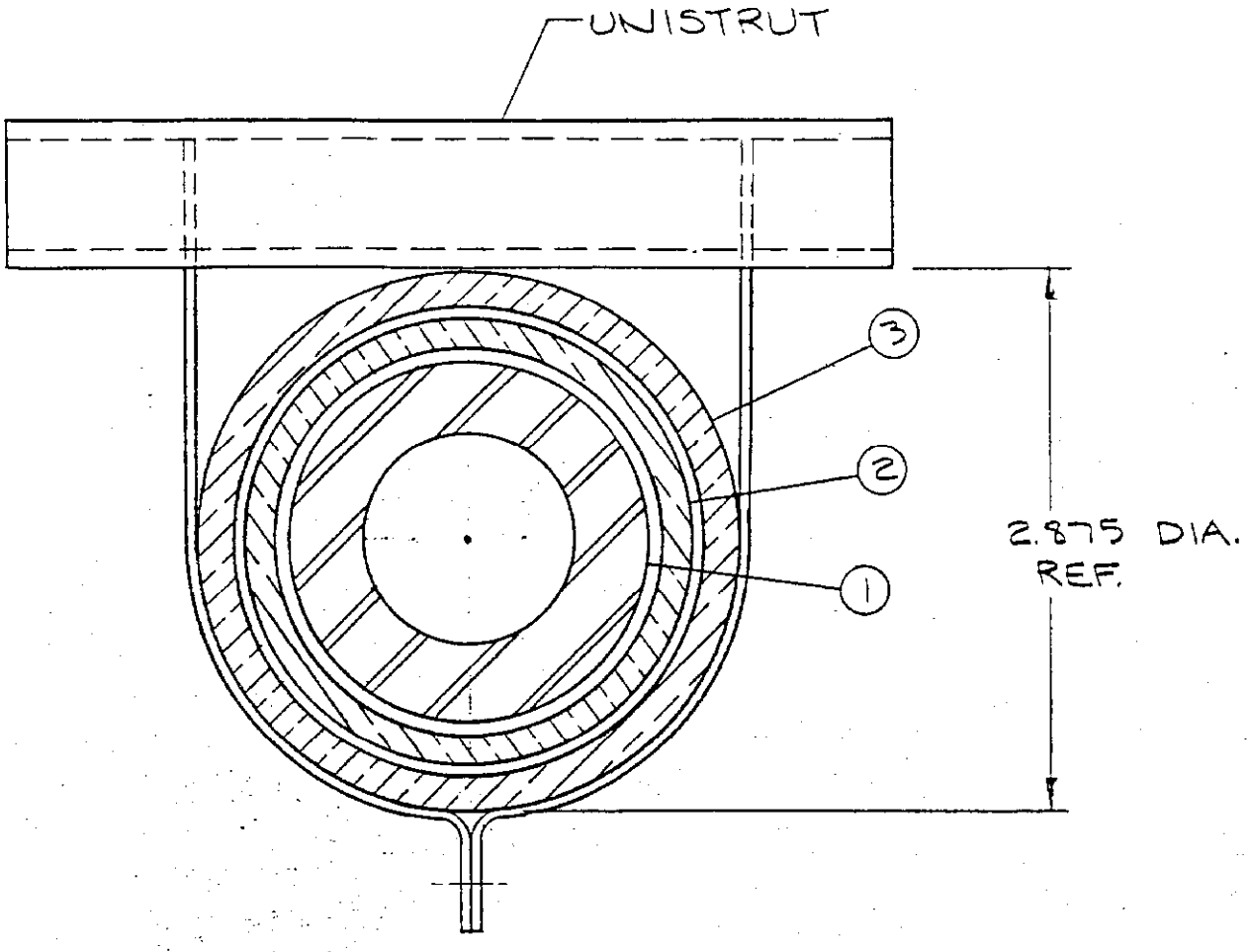
The average bus temperature rise is chosen at 10°C with 20°C water temp rise at the outlet.

Most bus runs installed in the field are about 500' or less. This length of bus will expand about 1". We have not used expansion joints, but use natural bends to take care of this expansion. The bus is not solidly anchored to building structures.

5. Acknowledgement

Stan Orr and Leon Beverly have ordered materials for and installed many feet of bus. They suggested to use heavy shrink on tubing over the field braze joints. A more cumbersome system using split PVC pipe and insulation materials was previously used. The bus material list is taken from their files.

ATV:plm

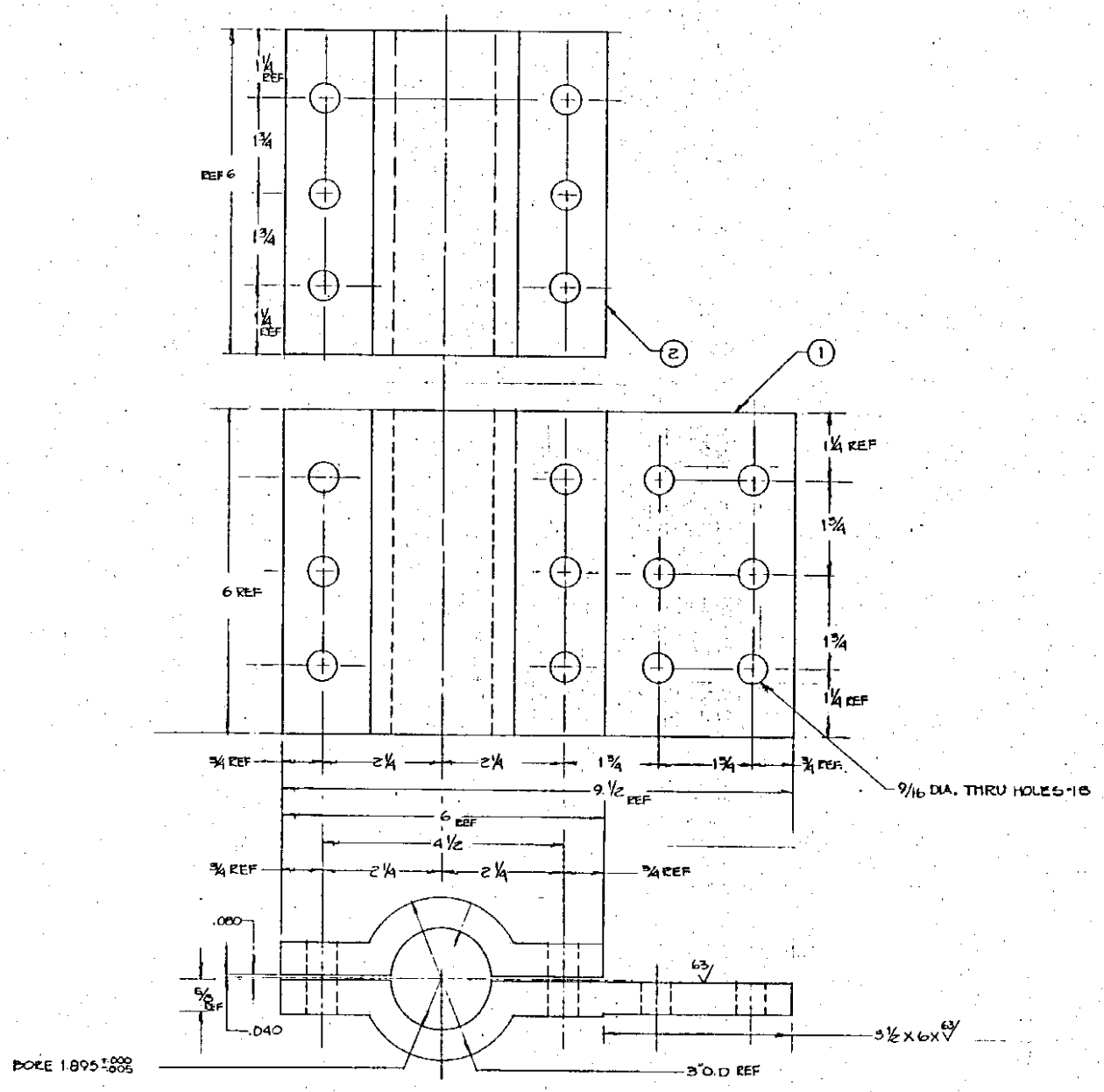


① COPPER PIPE

② INSULATING PIPE

③ SUPPORT PIPE

INSULATED WATERCOOLED BUS
TYPICAL CROSSECTION
FIG. 1 FULL SCALE



REV.	DESCRIPTION	DRAWN / APPD	DATE / DATE

ITEM NO	PART NO.	DESCRIPTION OR SIZE	QTY REQ
2	6004-ED-6812-2	BUSS CLAMP CAP	1
1	6004-ED-6812-1	BUSS CLAMP CABLE PLATE	1

PARTS LIST

UNLESS OTHERWISE SPECIFIED: FRACTIONS ± / DECIMALS ± .005 / ANGLES ±

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD.
√ MAX. ALL MACHINED SURFACES

ORIGINATOR	E. INNES	4-20-92
DRAWN	FERGUSON E	4-20-92
CHECKED		4-22-92
APPROVED		4/92

USED ON: 1½ WATER COOLED BUSS

MATERIAL: BRASS CASTING (85-5-5-5 METAL)

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

PROTON DEPT
5000A BUSS TERMINAL

SCALE	FINISH	DRAWING NUMBER	REV
FULL		6004-ED-76812	