TECHNICAL ANALYSIS #2

Problem

Civista is wired using copper conductors only. Copper is an expensive material that is some opinions, offers the same performance from a much cheaper aluminum alloy alternative.

Goal

To replace the existing copper feeders with aluminum alloy. An analysis of the new system will compare the alloy's safeness and practicality to that of copper. Finally, a cost analysis will prove the financial benefits associated with the new system.

Research Techniques

- Study existing conditions to gauge a firm understanding of the problem
- Interview construction team revision interests, concerns, and ideas
- Visit Civista for a firsthand evaluation
- Determine various solutions and individual benefits
- Determine a focused assessment of a solution to perform
- Perform analysis of proposed solution
- Publish a report of the Electrical revision that highlights benefits and advantages to the new system.

Expected Results

The expected results of this technical assignment will solve the indicated problem in a manner that proves safe, cost efficient, time efficient, and beneficial in any way to the problem.

Background

Copper was not always the monopoly it is today in electrical conductor types. Aluminum was used as far back as the 1930's and 1940's. But it wasn't until a copper shortage in 1965 forced the building industry towards copper's attractively cheaper alternative, aluminum. At the same time, receptacle brass screws faded from steel screws' newly established spotlight. Problems from all over began to surface. The newly established aluminum to steel connection was far more sensitive than copper to brass. Resulting faulty connections as well as many fires scared people into believing that aluminum as a conductor was just not worth the risk.

The aluminum and other connective devices were to code standards at the times of installation. However, as these problems persisted, the building industry realized that modifications were needed for the improvement of connections and terminations. *The Report of the Commission of Inquiry on Aluminum Building Wire* provided research findings of aluminum building wire systems (specifically branch circuits) in projects constructed between the years of 1941 and 1978. The in-depth evaluation highlighted factors related to the contact resistance of wiring. In total, the study identified 19 different issues impacting contact resistance. Improper installation, thermal expansion, and creep appeared to be the most common flaws.

Improper installation can be avoided through careful attention. This includes neat wiring that is suitably stripped with the appropriate tools, wrapped in a clockwise manner, and then sufficiently tightened. In addition, appropriate materials should be used. The use of appropriate tools decreases the chances of a nicked wire. This ensures a strong wire free from defect. Wrapping the wire in a clockwise direction along the terminal allows the wire to tighten as it is screwed into place. Proper tightening makes certain that there is adequate contact area at the connection. Finally, materials such as “push-in” terminals should be avoided altogether. Items like these are made for copper connections only and create a great hazard when used with aluminum.

The thermal expansion coefficient of aluminum is much greater than that of copper. When aluminum heats up, its diameter expands, and when it cools, it contracts. Previous copper wire classifications such as AA-1350 or EC (Electrical Conductor) aluminum would gradually loosen over each period of a heat and cool cycle from continuous volume differences. These differences then resulted in creep. Creep is the rate of change of a material’s permanent dimension deformation over a period of time when exposed to a force at a particular temperature. Today’s AA-8000 series aluminum alloys have creep rates very similar to copper building wire, resulting in similar performance. However, if connections are not properly installed (i.e. loose connection point), oxidation occurs and corrodes the contact area. The oxidation will increase the resistance (due to decrease contact area) and temperature. Eventually, the wire will consistently get very hot, melt the insulation or fixture, or may even cause a fire.

Figure 1: Aluminum Alloy (AA-8176) Conductors

NEC (National Electric Code)

The NEC first recognized aluminum wiring systems in 1901.

Conductor material **—** The NEC specifically requires aluminum conductors of most insulation types for branch-circuit wiring be made of AA-8000 series conductors. 2005 NEC Section 310.14

Physical characteristics **—** The NEC includes aluminum wire dimensions. It also includes some aluminum conductor electrical properties. Consult the conductor manufacturer for more specific properties.

Conduit fill **—** The NEC identifies conduit fill for compact stranded conductors based on the “(A)” tables in Annex C. These tables apply to both aluminum and copper compact stranded wire.

Terminations **—** The NEC requires that terminals used for aluminum be identified. It also requires that aluminum grounding electrode conductors used outdoors shall not be terminated within 18 inches of the earth.

Installation **–** The NEC references the National Electrical Installation Standards (NEIS). NECA/AA 104-2000 defines a minimum baseline of quality and workmanship for installing products and systems.

ASTM

AA-8000 series aluminum alloys were developed in the late 1960's. They began manufacturing it in 1972. The building wires are now manufactured according to the American Society for Testing and Materials (ASTM) B-800 and are generally compact stranded according to ASTM B-801.

UL (Underwriters Laboratories, Inc.)

In the early 1970's, Underwriters Laboratories removed their section on aluminum conductors for revision to require aluminum alloy conductors. Over the course of this modification, no new aluminum building wire was available for purchase except for what remained. By 1972, the aluminum alloy was being manufactured and sold. UL began listing only series AA-8000 types while at the same time also listing CO/ALR devices compatible with aluminum wire branch circuits. To this day, UL still only list AA-8000 types. These conductors require brass screws.

In 1978, UL issued standard UL486B for connectors for aluminum building wire. It contained more intense testing methods than what was previously required. Today, UL 486B has been combined with UL 486A and the combined standard contains requirements for both copper and aluminum wire connectors.

NFPA

All electrical connections should be periodically inspected in accordance with NFPA 70B.7

Physical Properties

Pre-1972 aluminum wiring was classified as type AA-1350, also known as EC (Electric Conductor) aluminum. This type of conductor consisted of approximately 99.5% pure aluminum. Copper is a far superior material compared to AA-1350.

Characteristic Differences Between Copper and Aluminum

Characteristic	Aluminum	Copper
Coefficient of Expansion per 1 °C @ 20°C	23×10^{-6}	16.6×10^{-6}
Thermal Conductivity (BTU/ft/hr/fft2/°F) @ 20°C	126	222
Electrical Conductivity (%IAS) at 20°C	61	101
Tensile Strength (lb/in^2) - (soft)	12,000	32,000

Table 1: Characteristic Differences Between Copper and Aluminum

However, today's AA-8000 aluminum alloy is much different than that of AA-1350. It contains 0.001 to 0.3% zinc, 0.001 to 0.03% titanium, 0.001 to 0.5% manganese, and 0.03 to 0.4% silicon, depending on product specification. This combination produces excellent strength and resistance to corrosion. Its composition is then made strong and flexible by annealing. Annealing is a process that heats the aluminum and then slowly cools it. By doing so, the material becomes suitable for bending and shaping the material and also prevents breaking and cracking.

AA-8000 has a higher strength-to-weight ratio than an equal ampacity copper wire. AA-8000 series is 0.006 lbs/cmil compared to 0.008 lbs/cmil for copper. It is also about half copper's weight. Since it is lighter, the pulling tension is lower. This is important when considering installation. Lower pulling tension may decrease the chances of damaging the insulated wire in doing so. Its only drawback is that its diameter is slightly larger (based on compact stranding) for equal an ampacity copper conductor.

Special Installation Requirements

There are far too many different connection types to explore each individual installation procedure. Instead, the use of oxide inhibitors and wire brushing will be discussed.

Terminating a conductor, both copper and AA-8000, requires similar steps. First, the insulation is stripped. Second, the exposed part of the conductor is wire brushed. Third, an oxide inhibitor is applied. Finally, the connector is tightened to the recommended value.

The exposed part of the conductor should be wire brushed to remove excessive oxide from the wire, pieces of insulation, or other contaminants that may obstruct the connection. Brush only in one direction and not too forceful. Forceful brushing can embed oxides in the wire. Also, be sure to use a brush that has only been used previously on aluminum.

A thin layer of oxide naturally forms on the exterior of aluminum and copper conductors. This layer is broken when the connection screw is physically tightened or the connection is crimped. Wire brushing will remove the oxide and prevent it from being embedded during installation.

An oxide inhibitor should be applied to all exposed parts of a conductor prior to installation. The inhibitor provides a physical barrier at the contact point that protects against moisture and other harmful substances. It's also an important feature to successfully connecting dissimilar metals. The oxide inhibitor must be compatible with the conductor type. Some compression type connectors may come pre-filled with the appropriate oxide inhibitor. Oxide inhibitor is important to uncoated connections between copper and aluminum. This type of connection is subject to galvanic corrosion.

Always consult the manufacture and product specifications to ensure proper installation. Not all connections may require wire brushing or oxide inhibitors.

Feeder Schedule

Feeder No.	Circuit Beaker Amp	No. of Sets	Wire Size Per Set	Ground Size Per Set	Conduit Size Per Set	Remarks
A	350	1	3-1C, #4/0 AWG	1-#2/0 AWG	4"	TYPE XLPE/EPR 15kV RATED
B	4000	10	4-#500 KCM	1-#500 MCM	4"	TYPE USE, 600V SERVICE ENTRANCE
C	1800	5	4-#500 KCM	1-#4/0 AWG	4"	THHN/THWN, 600V
D	1200	4	4-#500 KCM	1-#3/0 AWG	4"	THHN/THWN, 600V
E	1000	3	4-#500 KCM	1-#2/0 AWG	4"	THHN/THWN, 600V
F	800	2	3-#500 KCM	1-#2/0 AWG	4"	THHN/THWN, 600V
G	800	2	4-#500 KCMIL	1-#1/0 AWG	4"	THHN/THWN, 600V
H	800	2	4-#350 KCMIL	1-#1/0 AWG	3"	THHN/THWN, 600V
I	500	2	3-#300 KCMIL	1-#1/0 AWG	3"	THHN/THWN, 600V
J	500	2	4-#300 KCMIL	1-#1/0 AWG	3"	THHN/THWN, 600V
K	400	1	4-#500 KCM	1-#1/0 AWG	4"	THHN/THWN, 600V
L	300	1	4-#350 KCM	1-#1/0 AWG	3"	THHN/THWN, 600V
M	250	1	4-#250 KCMIL	1-#1 AWG	2-1/2"	THHN/THWN, 600V
N	225	1	4-#4/0 AWG	1-#2 AWG	2"	THHN/THWN, 600V
O	200	1	4-#3/0 AWG	1-#2 AWG	2"	THHN/THWN, 600V
P	150	1	4-#1/0 AWG	1-#4 AWG	1-1/2"	THHN/THWN, 600V
Q	100	1	4-#1 AWG	1-#4 AWG	1-1/2"	THHN/THWN, 600V
R	450	2	4-#250 KCMIL	1-#1 AWG	1-4"	THHN/THWN, 600V
S	60	1	4-#4 AWG	1-#8 AWG	1-1/4"	THHN/THWN, 600V
T	50	1	4-#8 KCM	1-#8 AWG	1"	THHN/THWN, 600V
U	30	1	4-#10 AWG	1-#10 AWG	3/4"	THHN/THWN, 600V
U'	30	1	3-#10 AWG	1-#10 AWG	3/4"	THHN/THWN, 600V
V	20	1	4-#12 AWG	1-#12 AWG	3/4"	THHN/THWN, 600V
W	60	1	3-#4 AWG	1-#6 AWG	1"	THHN/THWN, 600V

Copper Wiring and Conduit Costs										
FDR ID	**OCPD**	**Sets**	**Length (ft)**	**Copper Phase Wires**	**Copper Wire Unit Cost (per LF)**	**Copper Wire Costs**	**Conduit Size Per Set**	**EMT Conduit Unit Cost (per LF)**	**Conduit Costs**	**Total Cost per Feeder**
A	350	1	50	3-1C, #4/0 KCMIL	*** exceeds 600V ***					
B	4000	10	120	4-#500 KCMIL	$6.95	$834.00	4"	$27.50	$3,300.00	$4,134.00
C	1800	5	50	4-#500 KCMIL	$6.95	$347.50	4"	$27.50	$1,375.00	$1,722.50
D	1200	4	60	4-#500 KCMIL	$6.95	$417.00	4"	$27.50	$1,650.00	$2,067.00
E	1000	3	40	4-#500 KCMIL	$6.95	$278.00	4"	$27.50	$1,100.00	$1,378.00
F	800	2	80	3-#500 KCMIL	$6.95	$556.00	4"	$27.50	$2,200.00	$2,756.00
G	800	2	130	4-#500 KCMIL	$6.95	$903.50	4"	$27.50	$3,575.00	$4,478.50
H	800	2	110	4-#350 KCMIL	$5.45	$599.50	3"	$20.50	$2,255.00	$2,854.50
I	500	2	100	3-#300 KCMIL	$4.90	$490.00	3"	$20.50	$2,050.00	$2,540.00
J	500	2	100	4-#300 KCMIL	$4.90	$490.00	3"	$20.50	$2,050.00	$2,540.00
K	400	1	400	4-#500 KCMIL	$6.95	$2,780.00	4"	$27.50	$11,000.00	$13,780.00
L	300	1	200	4-#350 KCMIL	$5.45	$1,090.00	3"	$20.50	$4,100.00	$5,190.00
M	250	1	90	4-#250 KCMIL	$4.40	$396.00	2-1/2"	$16.10	$1,449.00	$1,845.00
N	225	1	1500	4-#4/0 KCMIL	$3.85	$5,775.00	2"	$10.20	$15,300.00	$21,075.00
O	200	1	70	4-#3/0 KCMIL	$3.25	$227.50	2"	$10.20	$714.00	$941.50
P	150	1	100	4-#1/0 KCMIL	$2.30	$230.00	1-1/2"	$8.65	$865.00	$1,095.00
Q	100	1	1500	4-#1 KCMIL	$1.92	$2,880.00	1-1/2"	$8.65	$12,975.00	$15,855.00
R	450	2	60	4-#250 KCMIL	$4.40	$264.00	2-1/2"	$16.10	$966.00	$1,230.00
S	60	1	130	4-#4 KCMIL	$1.25	$162.50	1-1/4"	$7.35	$955.50	$1,118.00
T	50	1	80	4-#8 KCMIL	$0.72	$57.60	1"	$5.75	$460.00	$517.60
U	30	1	220	4-#10 KCMIL	$0.56	$123.20	3/4"	$4.50	$990.00	$1,113.20
U'	30	1	160	3-#10 KCMIL	$0.56	$89.60	3/4"	$4.50	$720.00	$809.60
V	20	1	200	4-#12 KCMIL	$0.48	$96.00	3/4"	$4.50	$900.00	$996.00
W	60	1	150	3-#4 KCMIL	$1.25	$187.50	1"	$5.75	$862.50	$1,050.00
				TOTAL		**$19,274.40**			**$71,812.00**	**$91,086.40**
				TOTAL COPPER COSTS						**$91,086.40**

Aluminum Wiring and Conduct Costs										
FDR ID	**OCPD**	**Sets**	**Length (ft)**	**Aluminum Phase Wires**	**Aluminum Wire Unit Cost (per LF)**	**Aluminum Wire Costs**	**Conduit Size Per Set**	**EMT Conduit Unit Cost (per LF)**	**Conduit Costs**	**Total Cost per Feeder**
A	350	1	50	3-1C, #4/0 KCMIL	*** exceeds 600V ***					
B	4000	12	120	4-#500 KCMIL	$4.45	$534.00	4"	$27.50	$3,300.00	$3,834.00
C	1800	5	50	4-#500 KCMIL	$4.45	$222.50	4"	$27.50	$1,375.00	$1,597.50
D	1200	5	60	4-#400 KCMIL	$3.95	$237.00	3-1/2"	$25.00	$1,500.00	$1,737.00
E	1000	4	40	4-#400 KCMIL	$3.95	$158.00	3-1/2"	$25.00	$1,000.00	$1,158.00
F	800	3	80	3-#400 KCMIL	$3.95	$316.00	3-1/2"	$25.00	$2,000.00	$2,316.00
G	800	3	130	4-#400 KCMIL	$3.95	$513.50	3-1/2"	$25.00	$3,250.00	$3,763.50
H	800	3	110	4-#400 KCMIL	$3.95	$434.50	3-1/2"	$25.00	$2,750.00	$3,184.50
I	500	2	100	3-#400 KCMIL	$3.95	$395.00	3-1/2"	$25.00	$2,500.00	$2,895.00
J	500	2	100	4-#400 KCMIL	$3.95	$395.00	3-1/2"	$25.00	$2,500.00	$2,895.00
K	400	2	400	4-#250 KCMIL	$2.76	$1,104.00	2-1/2"	$16.10	$6,440.00	$7,544.00
L	300	1	200	4-#500 KCMIL	$4.45	$890.00	4"	$27.50	$5,500.00	$6,390.00
M	250	1	90	4-#350 KCMIL	$3.50	$315.00	3"	$10.20	$918.00	$1,233.00
N	225	1	1500	4-#300 KCMIL	$3.35	$5,025.00	3"	$10.20	$15,300.00	$20,325.00
O	200	1	70	4-#3/0 KCMIL	$2.25	$157.50	2"	$10.20	$714.00	$871.50
P	150	1	100	4-#1/0 KCMIL	$1.73	$173.00	1-1/2"	$8.65	$865.00	$1,038.00
Q	100	1	1500	4-#1 KCMIL	$1.51	$2,265.00	1-1/2"	$8.65	$12,975.00	$15,240.00
R	450	2	60	4-#250 KCMIL	$1.76	$105.60	2-1/2"	$16.10	$966.00	$1,071.60
S	60	1	130	4-#4 KCMIL	$0.95	$123.50	1-1/4"	$7.35	$955.50	$1,079.00
T	50	1	80	4-#8 KCMIL	$0.65	$52.00	1"	$5.75	$460.00	$512.00
U	30	1	220	4-#10 KCMIL	$0.50	$110.00	3/4"	$4.50	$990.00	$1,100.00
U'	30	1	160	3-#10 KCMIL	$0.50	$80.00	3/4"	$4.50	$720.00	$800.00
V	20	1	200	3-#12 KCMIL	$0.46	$92.00	3/4"	$4.50	$900.00	$992.00
W	60	1	150	3-#2 KCMIL	$1.20	$180.00	1-1/2"	$8.65	$1,297.50	$1,477.50
				TOTAL		**$13,878.10**			**$69,176.00**	**$83,054.10**
				TOTAL ALUMINUM COSTS						**$83,054.10**

Aluminum vs. Copper - Time Saved										
FDR ID	**Cu Sets**	**Al Sets**	**Length (ft)**	**Copper Wire Size**	**Daily Output (CLF)**	**Total Duration (days)**	**Aluminum Wire Size**	**Daily Output (CLF)**	**Total Duration (days)**	**Time Difference (days)**
A	1	1	50	3-1C, #4/0 KCMIL	*** exceeds 600V ***					
B	10	12	120	4-#500 KCMIL	4.8	2.500	4-#500 KCMIL	6	2.000	0.500
C	5	5	50	4-#500 KCMIL	4.8	0.521	4-#500 KCMIL	6	0.417	0.104
D	4	5	60	4-#500 KCMIL	4.8	0.500	4-#400 KCMIL	6.9	0.348	0.152
E	3	4	40	4-#500 KCMIL	4.8	0.250	4-#400 KCMIL	6.9	0.174	0.076
F	2	3	80	3-#500 KCMIL	4.8	0.333	3-#400 KCMIL	6.9	0.232	0.101
G	2	3	130	4-#500 KCMIL	4.8	0.542	4-#400 KCMIL	6.9	0.377	0.165
H	2	3	110	4-#350 KCMIL	5.4	0.407	4-#400 KCMIL	6.9	0.319	0.089
I	2	2	100	3-#300 KCMIL	5.7	0.351	3-#400 KCMIL	6.9	0.290	0.061
J	2	2	100	4-#300 KCMIL	5.7	0.351	4-#400 KCMIL	6.9	0.290	0.061
K	1	2	400	4-#500 KCMIL	4.8	0.833	4-#250 KCMIL	8.7	0.460	0.374
L	1	1	200	4-#350 KCMIL	5.4	0.370	4-#500 KCMIL	6	0.333	0.037
M	1	1	90	4-#250 KCMIL	6	0.150	4-#350 KCMIL	7.5	0.120	0.030
N	1	1	1500	4-#4/0 KCMIL	4.4	3.409	4-#300 KCMIL	8.1	1.852	1.557
O	1	1	70	4-#3/0 KCMIL	5	0.140	4-#3/0 KCMIL	6.6	0.106	0.034
P	1	1	100	4-#1/0 KCMIL	6.6	0.152	4-#1/0 KCMIL	8	0.125	0.027
Q	1	1	1500	4-#1 KCMIL	8	1.875	4-#1 KCMIL	9	1.667	0.208
R	2	2	60	4-#250 KCMIL	6	0.200	4-#250 KCMIL	8.7	0.138	0.062
S	1	1	130	4-#4 KCMIL	10.6	0.123	4-#4 KCMIL	13	0.100	0.023
T	1	1	80	4-#8 KCMIL	8	0.100	4-#8 KCMIL	9	0.089	0.011
U	1	1	220	4-#10 KCMIL	10	0.220	4-#10 KCMIL	11	0.200	0.020
U'	1	1	160	3-#10 KCMIL	10	0.160	3-#10 KCMIL	11	0.145	0.015
V	1	1	200	4-#12 KCMIL	11	0.182	3-#12 KCMIL	12	0.167	0.015
W	1	1	150	3-#4 KCMIL	10.6	0.142	3-#2 KCMIL	10.6	0.142	0.000
				TOTAL		**13.810**			**10.089**	**3.721**
				TOTAL TIME SAVED (Days)						**4**

Cost Comparison

Table 1 on the following page is the Feeder Schedule for Civista Medical Center. This schedule is used to compare cost and time savings by redesigning the currently installed copper feeder distribution system to that of aluminum. Following the Feeder Schedule are Table 2 and Table 3. These schedules resize the wires accordingly to over current protection as well as the conduit. Once resized, a cost analysis was preformed.

Copper Wiring Costs:	$19,274.40
Copper Conduit Costs:	$71,812.00
Total:	**$91,086.40**

Aluminum Wiring Costs:	$13,878.10
Aluminum Conduit Costs:	$69,176.00
Total:	**$83,054.10**

Total Cost Savings: **$8,032.30**

Finally, Table 4 displays the total time saved.

Copper Installation Duration:	13.810 days
Aluminum Installation Duration:	10.089 days

Total Time Savings: **4 days**

Conclusion

Modern aluminum alloy conductors are at least as safe and reliable as copper. Connections are evaluated and manufactured specifically for aluminum. AA-8000 series conductors have over 30 years of field installation examples proving their reliability and efficiency. They have been recognized in the NEC for more than 20 years as well as the UL.

Utilizing AA-8000 series conductors are also cost effective. On the Civista Medical Center project, the new addition alone saved over $8,000 and four days of installation time. With a project that over and over again proves to be safe, why not consider it as a legitimate option?