Sargent & Lundy

Calc. For Conductor Temperature in Conduits Wrapped with 1 Hour Darmatt Fire Barrier		**Calc. No.** PI-NSP-95-002
X **Safety-Related**	**Non-Safety-Related**	**Rev.** 1 **Date** 10/30/95
		Page 1 of 13

Client Northern States Power	**Prepared by** William G Blott **Date** Oct 26, 1995
Project Prairie Island Units 1 & 2	**Reviewed by** Vedal Doshi **Date** 10/26/95
Proj. No. 8960-08 **Equip. No.**	**Approved by** M E Hill **Date** 10/30/95

I. REVISION SUMMARY and REVIEW METHOD

A. Revision Summary

Revision 0; First Issue; pages 1 through 13
Appendix A; pages A1 through A50
Appendix B; pages B1 through B26
Appendix C; pages C1 through C49

Revision 1: Added cables 16407-1 and 15406-1
Pages 1 through 13
Appendix A; pages A1 through A62
Appendix B; pages B1 through B26
Appendix C; pages C1 through C49
Appendix D; pages D1 through D15

I REVISION SUMMARY and REVIEW METHOD (continued)

B. METHOD OF REVIEW

QA CALCULATION REVIEW CHECKLIST

TYPE OF CALCULATION

☒ Hand-Prepared Design Calculation Only

☐ Computer-Aided Design Calculation Only

☐ Both hand-Prepared and Computer Aided Design Calculation

FOR HAND-PREPARED DESIGN CALC
(check the appropriate items)

☒ Detailed review of the original calculation.

☐ Review by an alternate, simplified or approximate method of calculation.

☐ Review of a representative sample of repetitive calculations.

☐ Review of the calculation against a similar calculation previously performed.

FOR COMPUTER-AIDED DESIGN CALC
(check the appropriate items)

☐ A review to determine if the engineering design and analysis computer program(s) used have been validated and documented and that the calculation, regardless of the program used, contains all the necessary documentation for reconstruction at a later date. (MUST BE PERFORMED)

☐ A review to verify that the computer program is suitable to the problem being analyzed.(MUST BE PERFORMED)

☐ A review to determine if the input data as specified for program execution is consistent with the design input, correctly defines the problem for the computer program algorithm and is sufficiently accurate to produce results within any numerical limitation of the program. (MUST BE PERFORMED)

☐ A review to verify that the results obtained from the program are correct and within stated assumptions and limitations of the program and are consistent with the input. (MUST BE PERFORMED)

☐ Validation documentation for temporary changes to listed programs or developmental programs or unique single application programs shall be reviewed to assure that methods used adequately validate the program for the intended application. (WHERE APPLICABLE)

REVIEWER: Nedal Deeb DATE: 10/26/95

II. TABLE OF CONTENTS

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III. PURPOSE/SCOPE

A. Purpose

The purpose of this calculation is to determine the conductor temperature in conduits wrapped with 1 hour fire barrier utilizing Darmatt fire wrap material. The calculation will be based on the conductors carrying their full load current and ambient temperature of 40°C. The calculated conductor temperature is compared to the conductor rated temperature of 90°C to determine if the conductor rated temperature is exceeded.

B. Scope

The scope of this calculation is limited to calculating the conductors temperature wrapped with 1 hour Darmatt fire barrier and compare it to the conductors rated temperature of 90°C for the following cables at Prairie Island Power Plant: 121B-1, 121J-1, 121J-2, 1CA-1228, 1EMA-6, 1K2-18, 1K2-19, 1K2-20,1K2-7, 1K2-2, 2CA-601, 2EMA-6, 16407-1, and 15406-1.

IV. INPUT DATA

A. The conduit internal and external diameters based on the conduit nominal diameter sizes are taken from reference XII.C

Conduit Nominal size in inches	Diameter in inches Internal	External	Wall Thickness in inches
1.25	1.394	1.660	0.133
2.0	2.083	2.375	0.146
2.5	2.489	2.875	0.193
3.0	3.090	3.500	0.205
3.5	3.570	4.000	0.215
4.0	4.050	4.500	0.225

B. The conductor resistances and diameters are taken from reference XII.B

Cable Size	Resistance ohms/ft	Conductor Diameter (inch)
#10	0.0013	0.116
# 6	0.000513	0.184
#2	0.000203	0.292
#1/0	0.000128	0.373
#4/0	0.0000639	0.528
500 MCM	0.0000275	0.813

C. The following conduit and cable data are taken from References XII.E, XII.F, and XII.G:

Cable	Service	Cable Size	Cable Full Load Current (Amps)	Conduit Nominal Size
121B-1	MCC 1KA2 Feeder	1-3/C #4/0	0	2.5"
121J-1	MCC 1K2 Feeder	1-3/C 500 MCM	308	3.5"
121J-2	MCC 1K2 Feeder	1-3/C 500 MCM	308	3.5"
1CA-1228	PNL 1EMA Feeder	1-2/C #6	14.5	3" 3.5" ID**
1EMA-6	RMU 113 Bus 15 Feeder	1-3/C #10	0	3.5" ID**
1K2-18	Panel 135 Feeder	1-3/C #2	24	2" 2" ID*
1K2-7	13 CHG Pump	1-3/C #1/0	134	2" ID*
1K2-2	12 RHR Pit Sump Pump	1-3/C #10	3.8	1" ID*

IV INPUT DATA (continued)

Cable	Service	Cable Size	Cable Full Load Current (Amps)	Conduit Nominal Size
1K2-19	Panel 135 Feeder	3-1/C #2	46	1.25"
1K2-20	MV-32267	1-3/C #10	3.5	1" ID*
2CA-601	Panel 2EMA Feeder	1-2/C #6	14	3" 3.5" ID**
2EMA-6	RMU 213 Bus Rm 26 Feeder	1-5/C #12	0	3" 3.5" ID**
16407-1	12 SI Pump	1-3/C #2, 5 kV	100	4"
15406-1	Bus 112	1-3/C #4/0, 5 kV	102	3"

* cables are wrapped in KM1 conduit filled with thermal filler.
** cables are routed in the same 3" conduit and in the same 3.5" ID drop.

D. The rated conductor temperature is 90°C and ambient temperature is 40°C (References XII.E and XII.G)

E. The emissivity of the Darmatt surface is 0.7 (Reference XII.E)

F. The Darmatt material thermal conductivity is 0.783 BTU in/hr-ft^2-°F (0.0653 BTU/hr-ft-°F) (Reference XII.E)

G. The Stephan-Boltzman constant is equal to 0.1714X10^{-8} Btu/hr-ft^2-°R^4 (Reference XII.D)

H. The thermal resistivity of the cable insulation, jacket, and overall jacket is 500°C-cm/watt and 0.50°C-cm/watt for the armor (Reference XII.A)

I. The thermal resistivity of a steel conduit wall is 2.08 °C-cm/watt (Reference XII.A)

J. The following cable construction data are taken from reference XII.E

Cable size (inch)	Insulation Thickness (inch)	Individual Jacket Thickness (inch)	Overall Jacket Thickness (inch)	Armor Thickness (inch)
1-3/C #10	0.03	.015	0.06	0.025

IV INPUT DATA (continued)

Cable size (inch)	Insulation Thickness (inch)	Individual Jacket Thickness (inch)	Overall Jacket Thickness (inch)	Armor Thickness (inch)
1-2/C #6	0.045	0.025	0.08	0.025
1-3/C #2	0.045	0.025	0.08	0.025
1-3/C #1/0	0.055	0.03	0.08	0.025
3-1/C #2	0.062	-	0.03	-
3/C #2, 5 kV	8/64	5/64	See assumptions	See assumptions
3/C #4/0, 5 kV	8/64	6/64	See assumptions	See assumptions
500 MCM	0.065	-	0.110	0.025

K. The Darmatt layer nominal thickness for a 1 hour fire barrier is 1.25" (Reference XII.E)

L. The diameter of a 19 strand, #2 AWG conductor (Class C stranding), used for cable 16407-1, is $5 \times 0.0591 = 0.296$ inch (Reference XII.H)

V. ASSUMPTIONS

A. Assumptions Not Requiring Verification

1. The thickness of the armor of cables 16407-1 and 15406-1 is assumed to be the same as for the other cables (0.025"). The thickness of the overall jacket is assumed to be that thickness required to fill the space between the inside of the armor and the circumscribed diameter of the three conductors with their insulation and individual jackets. Since minor variations in the overall jacket thickness will not have a major effect on the conductor temperature, this assumption does not require verification.

2. This calculation will consider the main run of conduit as a worst case. Because of their larger surface area, the temperature of an enclosure, such as a pull box, will be lower to dissipate the same amount of heat compared to the main conduit run. Since the temperature rise between the inside of an enclosure or conduit is treated as a film temperature drop at the surface of the cable, a lower enclosure surface temperature will result in lower cable and conductor temperatures. This assumption does not require verification.

VI. ACCEPTANCE CRITERIA

The conductor temperature when carrying the full load current should not exceed the cable continuous rated temperature of 90°C.

VII. METHODOLOGY

A. Calculate the amount of heat generated by the conductors inside the conduit based on the conductors carrying the full load current and a conductor resistance at 90°C.

B. Calculate the amount of heat dissipated by convection and radiation from the outside of the Darmatt wrap based on an ambient temperature of 40°C and a surface temperature which will allow the heat dissipated by convection and radiation from the Darmatt layer surface to equal the amount of heat generated by the conductors inside the conduit.

C. The Darmatt wrap surface temperature will be calculated iteratively using the MATHCAD computer program until the amount of heat dissipated by convection and radiation from the outside of the Darmatt wrap equals the amount of heat generated by the cable inside the conduit

D. The temperature drop due to the conduction of heat through the following layers is calculated based on the heat generated by the conductors inside the conduit and the thermal resistance of each layer:

- The Darmatt mass from the outside surface of the conduit (for cables in condiut) or the cable jacket (for cables routed without conduit) to the outside surface of the Darmatt
- From the inside surface to the outside surface of the conduit (for cables routed in conduit)
- Through the air gap between the outside surface of the cable and the inside surface of the conduit (for cables routed in conduit)
- The temperature drop from the metal conductor surface to the cable surface (through the conductor insulation, jacket,..etc.)

E. The temperature drop through the Darmatt wrap, the conduit, the air space between the cable surface and the inside surface of the conduit and the metal conductor surface to the cable surface will be added to the Darmatt wrap surface temperature to determine the conductor temperature. This value will then be compared to the conductor rated temperature to determine if the conductor calculated temperature exceeds the conductor rated temperature of 90°C when the conductors carry the full load current.

F. Cables No. 121B-1, 1EMA-6 and 2EMA-6 feed intermittent loads. Therefore, calculating the conductor temperature is not necessary since the loads fed by those cables are only energized for a short period of time.

VIII. CALCULATIONS and RESULTS

Refer to Appendix A for the calculation of the conductor temperature in conduits wrapped with 1 hour fire barrier.

IX. COMPARISON of RESULTS with ACCEPTANCE CRITERIA

The following is a comparison between the conductors calculated temperature and the conductor rated temperature:

Cable No.	Cable Size	Full Load Current (Amps)	Conductor Rated Temperature (°C)	Conductor Calculated Temperature (°C)	Pass/ Fail
121B-1	1-3/C 4/0	0	90	*	pass
121J-1	1-3/C 500 MCM	308	90	77.8	pass
121J-2	1-3/C 500 MCM	308	90	77.8	pass
1CA-1228	1-2/C #6	14.5	90	42.8 (Conduit) 43.7 (Drop)	pass
1EMA-6	1-3/C #10	0	90	*	pass
1K2-18	1-3/C #2	24	90	42.8 (Conduit) 43.1(Drop)	pass
1K2-19	3-1/C #2	46	90	52.9	pass
1K2-7	1-3/C 1/0	134	90	91.8	fail
1K2-2	1-3/C #10	3.8	90	40.6	pass
1K2-20	1-3/C #10	3.5	90	40.5 (Conduit) 40.6 (Drop)	pass
2CA-601	1-2/C #6	14	90	42.8 (Conduit) 43.7 (Drop)	pass
2EMA-6	1-5/C #12	0	90	*	pass
16407-1	1-3/C #2, 5 kV	100	90	78.6	pass
15406-1	1-3/C #4/0, 5 kV	102	90	52.1	pass

* Cables are feeding intermittent loads which are only energized for short period of time.

X. CONCLUSIONS

The conductor temperature for cables No. 121J-1, 121J-2, 1CA-1228, 1K2-18, 1K2-219, 1K2-7, 1K2-2, 1K2-20, 2CA-601, 16407-1, and 15406-1 installed in conduits wrapped with 1 hour fire barrier utilizing Darmatt material were calculated. It was found that the conductor temperatures are below the conductor rated temperature when those conductors carry load current except for cable 1K2-7.

As of the approval date of the calculation, cables 1K2-20, 1K2-2, 1K2-7, and 1K2-18 will not be wrapped due to pending rerouting of the cable and Appendix R revisions. Should it be decided to wrap cable 1K2-7, additional calculations must be performed to justify the ampacity of this cable.

XI. RECOMMENDATIONS

N/A

XII. REFERENCES

A. Sargent & Lundy Standard ESA-105 "Electrical Engineering Reference for Calculating Conductor Temperature of Power Cables", Rev. 8-4-95. This reference provides the formulas for calculating the temperature drop from the conductor surface to the inside surface of the Darmatt layer.

B. Sargent & Lundy Standard ESA-102 "Electrical Engineering Standard for Electrical and Physical Characteristics of Class B Cable", Rev. 4-14-93. This reference provided the cables resistances and diameters.

C. ANSI C80.1-1990, "Standard for Rigid Steel Conduit", Approved August 31,1990. This reference provided the conduit inside and outside diameters based on the conduit nominal diameter.

D. Heat Transfer Book, by J. P. Holman, McGraw Hill Book Company, Second Edition (1968). This reference provided Stephan-Boltzman constant, and the convection and radiation heat transfer formulas.

E. Sargent & Lundy Design Information Transmittal (DIT) No. PI-0001-01, dated 6/21/95. This reference provided information on the cable, Darmatt material,..etc.

F. Sargent & Lundy Design Information Transmittal (DIT) No. PI-0002-00, dated August 25, 1995. This DIT contains drawings giving information on cable routing and construction. Information was taken from the following drawings:
Drawing No. 1) 58-RW-C01, Rev. 0, dated August 9, 1995
2) 58-RW-C02, Rev. 0, dated August 9, 1995
3) 58-RW-T, Rev. 0, dated August 9, 1995
4) 58-CP-C02, Rev. 0, dated August 9, 1995
5) 59-CP-C01, Rev. 0, dated August 9, 1995
6) 59-MT-C01, Rev. 0, dated July 13, 1995
These drawings provided the cable routing and construction.

G. Sargent & Lundy Design Information Transmittal (DIT) No. PI-0003-01, dated September 20, 1995. This DIT provides information on cables 16407-1 and 15406-1.

H. ASTM Standard B8-81, "Standard Specification for Concentric-Lay-Stranded Conductors, Hard, Medium-Hard, or Soft

XIII. APPENDICES

Appendix A— Calculation of the Conductor Temperature

Appendix B— Design Information Transmittal PI-0001-00

Appendix C— Design Information Transmittal PI-0002-00

Appendix D— Design Information Transmittal PI-0003-01

APPENDIX A

CALCULATION OF THE CONDUCTOR TEMPERATURE

A. MCC 1K2 FEEDER - CABLE No. 121J-1 & 121J-2 (3/C - 500 MCM) (file: 121J_12.mcd)

1) Calculation of the Heat Generated in the Conduit

$I_{cond} = 308$ — I_{cond} is the conductor current in amps

$R_{cond} = 0.0000275$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} = 3$ — n_{cond} is the number of conductors in conduit

$Q_{cond} = (3.41443)\cdot(n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watt/ft to Btu/hr-ft

$Q_{cond} = 26.722$

$Q_{condw} = (n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in watt/ft

$Q_{condw} = 7.826$

2) Total Heat Transferred from the Wrapped Conduit

$T_{am} = 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} = (T_{am} + 273)\cdot\frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft^2-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) = t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} = 90$ — T_{cr} is the conductor rated temperature in degrees Celcius

$t_{darmatt} = 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{condout} = 4.0$ — $D_{condout}$ is the outside diameter of the conduit in inches

$D_{darmout} = D_{condout} + 2\cdot t_{darmatt}$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmout} = 6.5$

a) Calculation of the Heat Transferred by Convection from the Wrapped Conduit

$$h_c(t) = 0.27\cdot\left[\frac{T_{sw}(t) - T_{ar}}{\left(\frac{D_{darmout}}{12}\right)}\right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- °F (Ref. XII.D, Table 7-4, Horizontal Cylinders)

$A_w = \pi \cdot \frac{(D_{darmout})}{12}$ — A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$A_w = 1.702$

$Q_c(t) = h_c(t) \cdot A_w \cdot (T_{sw}(t) - T_{ar})$ — Q_c is the heat transferred by convection from the wrappd conduit surface in Btu/hr-ft

b) Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface

$\sigma = 0.1714 \cdot 10^{-8}$ — Stephan-Boltzman constant in $Btu/hr\text{-}ft^2\text{-}R^4$

$\varepsilon_w = 0.7$ — Emissivity of the wrapped conduit surface (Darmatt)

$Q_r(t) = \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[(T_{sw}(t))^4 - (T_{ar})^4 \right]$ — Qr is the heat transferred by radiation to the surroundings from the wrapped conduit in Btu/hr-ft

c) Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface

$Q_{cr}(t) = Q_c(t) + Q_r(t)$ — Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to its surroundings

$t = 550$

Given

$Q_{cond} = Q_{cr}(t)$

$T_{surface} = Find(t)$ — $T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface equal to the heat generated by the cable inside the conduit

$T_{surface} = 574.201$

$h_c(T_{surface}) = 0.571$ $Q_r(T_{surface}) = 16.235$ $Q_c(T_{surface}) = 10.487$

$Q_{cr}(T_{surface}) = 26.722$

3) Temperature Drop Through the Darmatt Layer

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft²-ºF

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ftºF

$K_{darmatt} = 0.065$

$D_{darmout} = 6.5$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmin} = D_{condout}$

D_{darmin} is the inside diameter of the Darmatt in inches or the outside diameter of the conduit

$$R_{darmatt} = \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot\ln\left(\frac{D_{darmout}}{D_{darmin}}\right)$$

$R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watts

$R_{darmatt} = 1.184$

$\Delta T_{darmatt} = Q_{cond} \cdot R_{darmatt}$

$\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 31.645$

$$\Delta T_{darmattc} = \left(\frac{5}{9}\right)\cdot\Delta T_{darmatt}$$

$\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 17.581$

4) <u>Temperature Drop Through the Conduit Wall</u>

$D_{conduit} = 3.5$ — $D_{conduit}$ is the nominal diameter of the conduit in inches

$D_{condout} = 4$ — $D_{condout}$ is the outside diameter of the conduit in inches

$t_{cond} = 0.215$ — t_{cond} is the conduit wall thickness in inches

$D_{condin} = D_{condout} - 2\cdot t_{cond}$ — D_{condin} is the inside diameter of the conduit in inches

$D_{condin} = 3.57$

$\rho_{cond} = 2.08$ — ρ_{cond} is the thermal resistivity of the conduit material in °C-cm/watt

$$R_{cond} = 0.00522\cdot\rho_{cond}\cdot\ln\left(\frac{D_{condout}}{D_{condin}}\right)$$

R_{cond} is the thermal resistance of the conduit in °C-ft/watt, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π)(1ft/12in)(0.3937in/cm)}

$R_{cond} = 0.001$

$\Delta T_{conduit} = Q_{condw} \cdot R_{cond}$

$\Delta T_{conduit}$ is the temperature drop through the conduit in °C

$\Delta T_{conduit} = 0.01$

5) Calculation of the Temperature drop through the Air Space Between the Cable Surface and the Inside Surface of the Conduit

$A' = 3.2$
$B' = 0.19$

A` & B` are constants used to determine the thermal resistance between the cable surface and the inside surface of the conduit

$D_{cable} = 2.297$

D_{cable} is the diameter of the group of conductors inside the conduit in inches determined in section 6

$$R_{sc} = \frac{A'}{D_{cable} + B'}$$

R_{sc} is the thermal resistance of the air gap between the cable surface and the inside surface of the conduit in °C-ft/watt

$R_{sc} = 1.287$

$\Delta T_{air} = Q_{condw} \cdot R_{sc}$

ΔT_{air} is the temperature drop in the air space between the cable surface and the inside surface of the conduit in °C

$\Delta T_{air} = 10.07$

6) Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable

$\rho_i = 500$ — ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watts

$\rho_j = 500$ — ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watts

$\rho_{3j} = 0.5$ — ρ_{3j} is the thermal resistivity of the armor in °C-cm/watt

$t_i = .065$ — t_i is the insulation thickness in inches

$t_j = 0.0$ — t_j is the individual jacket thickness in inches

$t_{oj} = 0.110$ — t_{oj} is the overall jacket thickness in inches

$t_a = 0.025$ — t_a is the armor thickness in inches

$d = 0.813$ — d is the diameter of the conductor metal of one conductor in inches

$d_j = d + 2 \cdot t_j + 2 \cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.943$

$d_i = d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.943$

$d_{3j\phi} = 2.15 \cdot d_j + 2 \cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches

$d_{3j\phi} = 2.247$

$d_{3ju} = d_{3j\phi} - 2 \cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 2.027$

$d_{arm} = d_{3j\phi} + 2 \cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 2.297$

$$R_{ij} = 0.00522 \cdot \left[2 \cdot \left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right) \right) + 3 \cdot \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + 3 \cdot \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right) \right]$$

$R_{ij} = 1.581$ — R_{ij} is the thermal resistance from the metal conductor surface to the surface of the cable in °C-ft/watt, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π) (1ft/12in)(0.3937in/cm)}.

$$\Delta T_{cable} = \frac{Q_{condw}}{3} \cdot R_{ij}$$

ΔT_{ij} is the tempreture drop from the surface of the one metal conductor to the surface of the cable in °C

$\Delta T_{cable} = 4.125$

7) Conductor Temperature

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$$\Delta T_{total} = \Delta T_{darmatte} + \Delta T_{conduit} + \Delta T_{air} + \Delta T_{cable}$$

ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$\Delta T_{total} = 31.785$

$$T_{conductor} = \left| T_{surface} \left(\frac{5}{9}\right) - 273 \right| + \Delta T_{total}$$

$T_{conductor}$ is the conductor temperature in °C

$T_{conductor} = 77.786$

B. PANEL 135 FEEDER - CABLE No. 1K2-18 (1 - 3/C #2) (file: 1K2_18.mcd)

1) Calculation of the Heat Generated by the Conductors

$I_{cond} := 24$ — I_{cond} is the conductor current in amps

$R_{cond} := 0.000203$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 3$ — n_{cond} is the number of conductors in conduit

$Q_{cond} := (3.41443) \cdot (n_{cond}) \cdot (I_{cond})^2 \cdot (R_{cond})$ — Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{cond} = 1.198$

$Q_{condw} := (n_{cond}) \cdot (I_{cond})^2 \cdot (R_{cond})$ — Q_{cond} is the heat generated in the conduit in watt/ft

$Q_{condw} = 0.351$

2) Total Heat Transferred from the Wrapped Cable

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273) \cdot \frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft^2-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{darmout} := 4.5$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

a) Calculation of the Heat Transferred by Convection from the Wrapped Cable

$$h_c(t) = 0.27 \cdot \left[\frac{(T_{sw}(t) - T_{ar})}{\left(\frac{D_{darmout}}{12}\right)} \right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- ^oF (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w = \pi \cdot \frac{(D_{darmout})}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$$A_w = 1.178$$

$$Q_c(t) = h_c(t) \cdot A_w \cdot (T_{sw}(t) - T_{ar})$$

Q_c is the heat transferred by convection from the wrappd conduit surfece in Btu/hr-ft

b) Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface

$\sigma = 0.1714 \cdot 10^{-8}$ Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w = 0.7$ Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) = \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[(T_{sw}(t))^4 - (T_{ar})^4 \right]$$

Qr is the heat transferred by radiation to its surroundings from the wrapped conduit in Btu/hr-ft

c) Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface

$$Q_{cr}(t) = Q_c(t) + Q_r(t)$$

Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to its surroundings

$t = 550$

Given

$Q_{cond} = Q_{cr}(t)$

$T_{surface} = \text{Find}(t)$

$T_{surface} = 564.253$

$T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface equal to the heat generated by the cable inside the conduit

$h_c(T_{surface}) = 0.332$ $Q_r(T_{surface}) = 0.864$ $Q_c(T_{surface}) = 0.333$

$Q_{cr}(T_{surface}) = 1.198$

3) **Temperature Drop Through the Darmatt Layer**

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft^2-°F

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft°F

$K_{darmatt} = 0.065$

$D_{darmout} = 4.5$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{cable} = 1.139$ — D_{cable} is the diameter of the cable in inches

$$R_{darmatt} = \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot\ln\left(\frac{D_{darmout}}{D_{cable}}\right)$$

$R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watts

$R_{darmatt} = 3.351$

$\Delta T_{darmatt} = Q_{cond} \cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 4.014$

$\Delta T_{darmattc} = \left(\frac{5}{9}\right)\cdot\Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 2.23$

4) **Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable**

$\rho_i = 500$ — ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watts

$\rho_j = 500$ — ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watt

$\rho_{3j} = 0.5$ — ρ_{3j} is the thermal resistivity of the armor in °C-cm/watt

$t_i = .045$ — t_i is the insulation thickness in inches

$t_j = 0.025$ — t_j is the individual jacket thickness in inches

$t_{oj} = 0.08$ — t_{oj} is the overall jacket thickness in inches

$t_a = 0.025$ — t_a is the armor thickness in inches

$d = 0.292$ — d is the diameter of the conductor metal of one conductor in inches

$d_j = d + 2 \cdot t_j + 2 \cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.432$

$d_i = d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.382$

$d_{3j\phi} = 2.15 \cdot d_j + 2 \cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches

$d_{3j\phi} = 1.089$

$d_{3ju} = d_{3j\phi} - 2 \cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 0.929$

$d_{arm} = d_{3j\phi} + 2 \cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 1.139$

$$R_{ij} = 0.00522 \cdot \left[2 \cdot \left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right) \right) + 3 \cdot \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + 3 \cdot \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right) \right]$$

$R_{ij} = 3.289$ — R_{ij} is the thermal resistance from the metal conductor surface to the surface of the cable in °C-ft/watt, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π) (1ft/12in)(0.3937in/cm)}.

$$\Delta T_{cable} = \frac{Q_{condw}}{3} \cdot R_{ij}$$

$\Delta T_{cable} = 0.385$ — ΔT_{ij} is the tempreture drop from the surface of the one metal conductor to the surface of the cable in °C

5) **Conductor Temperature**

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$\Delta T_{total} = \Delta T_{darmattc} + \Delta T_{cable}$ — ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$\Delta T_{total} = 2.615$

$$T_{conductor} = \left[T_{surface} \cdot \left(\frac{5}{9}\right) - 273 \right] + \Delta T_{total}$$

$T_{conductor}$ is the conductor temperature in °C

$T_{conductor} = 43.088$

C. PANEL 135 FEEDER - CABLE No. 1K2-19 (3-1/C #2)

(file: 1K2_19.mcd)

1) Calculation of the Heat Generated in the Conduit

$I_{cond} := 46$ — I_{cond} is the conductor current in amps

$R_{cond} := 0.000203$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 3$ — n_{cond} is the number of cables in conduit

$Q_{cond} := (3.41443)\cdot(n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{cond} = 4.4$

$Q_{condw} := (n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in watt/ft

$Q_{condw} = 1.289$

2) Total Heat Transferred from the Wrapped Conduit

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273)\cdot\frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft²-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{condout} := 1.660$ — $D_{condout}$ is the outside diameter of the conduit in inches

$D_{darmout} := D_{condout} + 2\cdot t_{darmatt}$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmout} = 4.16$

a) Calculation of the Heat Transferred by Convection from the Wrapped Conduit

$$h_c(t) := 0.27 \cdot \left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)} \right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- ^{o}F (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w := \pi \cdot \frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$$A_w = 1.089$$

$$Q_c(t) := h_c(t) \cdot A_w \cdot \left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrapped conduit surface in Btu/hr-ft

b) Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface

$\sigma := 0.1714 \cdot 10^{-8}$ Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w := 0.7$ Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) := \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4 \right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface

$$Q_{cr}(t) := Q_c(t) + Q_r(t)$$

Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to its surroundings

$t := 550$

Given

$Q_{cond} = Q_{cr}(t)$

$T_{surface} := \mathrm{Find}(t)$

$T_{surface} = 566.438$

$T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface equal to the heat generated by the cable inside the conduit

$h_c\left(T_{surface}\right) = 0.465$ $Q_r\left(T_{surface}\right) = 2.863$ $Q_c\left(T_{surface}\right) = 1.537$

$Q_{cr}\left(T_{surface}\right) = 4.4$

3) Temperature Drop Through the Darmatt Layer

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft^2-°F

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft°F

$K_{darmatt} = 0.065$

$D_{darmout} = 4.16$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmin} = D_{condout}$ — D_{darmin} is the inside diameter of the Darmatt in inches or the outside diameter of the conduit

$$R_{darmatt} = \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot \ln\left(\frac{D_{darmout}}{D_{darmin}}\right)$$

$R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watts

$R_{darmatt} = 2.241$

$\Delta T_{darmatt} = Q_{cond} \cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 9.86$

$\Delta T_{darmattc} = \left(\frac{5}{9}\right)\cdot \Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 5.478$

4) Temperature Drop Through the Conduit Wall

$D_{conduit} = 1.25$ — $D_{conduit}$ is the nominal diameter of the conduit in inches

$D_{condout} = 1.66$ — $D_{condout}$ is the outside diameter of the conduit in inches

$t_{cond} = 0.133$ — t_{cond} is the conduit wall thickness in inches

$D_{condin} = D_{condout} - 2\cdot t_{cond}$ — D_{condin} is the inside diameter of the conduit in inches

$D_{condin} = 1.394$

$\rho_{cond} = 2.08$ — ρ_{cond} is the thermal resistivity of the conduit material in °C-cm/watt

$R_{cond} = 0.00522 \cdot \rho_{cond} \cdot \ln\left(\frac{D_{condout}}{D_{condin}}\right)$

$R_{cond} = 0.002$

R_{cond} is the thermal resistance of the conduit in °C-ft/watt, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π)(1ft/12in)(0.3937in/cm)}

$\Delta T_{conduit} = Q_{condw} \cdot R_{cond}$

$\Delta T_{conduit}$ is the tempreture drop through the conduit in °C

$\Delta T_{conduit} = 0.002$

5) Calculation of the Temperature drop through the Air Space Between the Cable Surface and the Inside Surface of the Conduit

$A' = 3.2$
$B' = 0.19$

A` & B` are constants used to determine the thermal resistance between the cable surface and the inside surface of the conduit

$D_{1c} = 0.476$

D_{1c} is the overall diameter of 1/C #2 in inches calculated in section 6

$D_{cable} = 2.15 \cdot D_{1c}$

$D_{cable} = 1.023$

D_{cable} is the diameter of the 3-1/C #2 inside the conduit in inches

$R_{sc} = \frac{A'}{D_{cable} + B'}$

R_{sc} is the thermal resistance of the air gap between the cable surface and the inside surface of the conduit in °C-ft/watt

$R_{sc} = 2.637$

$\Delta T_{air} = Q_{condw} \cdot R_{sc}$

ΔT_{air} is the temperature drop in the air space between the cable surface and the inside surface of the conduit in °C

$\Delta T_{air} = 3.398$

6) Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable

$\rho_i = 500$

ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watt

$\rho_j = 500$

ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watts

$\rho_{3j} = 50$

ρ_{3j} is the thermal resistivity of the armor in °C-cm/watts

$t_i = .062$ — t_i is the insulation thickness in inches

$t_{oj} = 0.03$ — t_{oj} is the overall jacket thickness in inches

$d = 0.292$ — d is the diameter of the conductor metal of one conductor in inches

$d_i = d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.416$

$d_s = d_i + 2 \cdot t_{oj}$ — d_s is the cable overall diameter in inches

$d_s = 0.476$

$d_j = d_s$ — d_j is the diameter over the jacket in inches

$$R_{ij} = 0.00522 \cdot (2) \cdot \left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_s}\right) \right)$$

$R_{ij} = 1.848$

R_{ij} is the thermal resistance from the metal conductor surface to the surface of the cable in °C-ft/watts, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π)(1ft/12in)(0.3937in/cm)}

$\Delta T_{cable} = Q_{condw} \cdot R_{ij}$ — ΔT_{ij} is the tempreture drop from the surface of the metal conductor to the surface of the cable in °C

$\Delta T_{cable} = 2.381$

7) Conductor Temperature

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$$\Delta T_{total} = \Delta T_{darmattc} + \Delta T_{conduit} + \Delta T_{air} + \Delta T_{cable}$$

ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$\Delta T_{total} = 11.259$

$$T_{conductor} = \left[T_{surface} \cdot \left(\frac{5}{9}\right) - 273 \right] + \Delta T_{total}$$

$T_{conductor}$ is the conductor temperature in °C

$T_{conductor} = 52.947$

D. MV-32267 - CABLE No. 1K2-20 (1 - 3/C #10) (file: 1K2_20.mcd)

1) Calculation of the Heat Generated by the Conductors

$I_{cond} := 3.5$ — I_{cond} is the conductor current in amps

$R_{cond} := 0.0013$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 3$ — n_{cond} is the number of conductors in conduit

$Q_{cond} := (3.41443) \cdot (n_{cond}) \cdot (I_{cond})^2 \cdot (R_{cond})$ — Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{cond} = 0.163$

$Q_{condw} := (n_{cond}) \cdot (I_{cond})^2 \cdot (R_{cond})$ — Q_{cond} is the heat generated in the conduit in watt/ft

$Q_{condw} = 0.048$

2) Total Heat Transferred from the Wrapped Cable

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273) \cdot \frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft^2-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{darmout} := 3.5$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

a) Calculation of the Heat Transferred by Convection from the Wrapped Cable

$$h_c(t) := 0.27 \cdot \left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)} \right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- ^oF (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w := \pi \cdot \frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$$A_w = 0.916$$

$$Q_c(t) := h_c(t) \cdot A_w \cdot \left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrappd conduit surfece in Btu/hr-ft

b) Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface

$\sigma := 0.1714 \cdot 10^{-8}$ Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w := 0.7$ Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) := \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4\right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface

$$Q_{cr}(t) := Q_c(t) + Q_r(t)$$

Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to the surrounding

$t := 550$

Given

$Q_{cond} = Q_{cr}(t)$

$T_{surface} := Find(t)$

$T_{surface} = 563.563$

$T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface equal to the heat generated by the cable inside the conduit

$h_c\left(T_{surface}\right) = 0.233$ $Q_r\left(T_{surface}\right) = 0.128$ $Q_c\left(T_{surface}\right) = 0.035$

$Q_{cr}\left(T_{surface}\right) = 0.163$

3) Temperature Drop Through the Darmatt Layer

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft²-°F

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft°F

$K_{darmatt} = 0.065$

$D_{darmout} = 3.5$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{cable} = 0.613$ — D_{cable} is the diameter of the cable in inches

$R_{darmatt} = \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot\ln\left(\frac{D_{darmout}}{D_{cable}}\right)$ — $R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watt

$R_{darmatt} = 4.249$

$\Delta T_{darmatt} = Q_{cond} \cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 0.693$

$\Delta T_{darmattc} = \left(\frac{5}{9}\right)\cdot\Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 0.385$

4) Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable

$\rho_i = 500$ — ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watts

$\rho_j = 500$ — ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watts

$\rho_{3j} = 0.5$ — ρ_{3j} is the thermal resistivity of the armor in °C-cm/watts

$t_i = .03$ — t_i is the insulation thickness in inches

$t_j = 0.015$ — t_j is the individual jacket thickness in inches

$t_{oj} = 0.06$ — t_{oj} is the overall jacket thickness in inches

$t_a = 0.025$ — t_a is the armor thickness in inches

$d = 0.116$ — d is the diameter of the conductor metal of one conductor in inches

$d_j = d + 2 \cdot t_j + 2 \cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.206$

$d_i = d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.176$

$d_{3j\phi} = 2.15 \cdot d_j + 2 \cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches

$d_{3j\phi} = 0.563$

$d_{3ju} = d_{3j\phi} - 2 \cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 0.443$

$d_{arm} = d_{3j\phi} + 2 \cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 0.613$

$$R_{ij} = 0.00522 \cdot \left[2 \cdot \left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right) \right) + 3 \cdot \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + 3 \cdot \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right) \right]$$

$R_{ij} = 4.876$ — R_{ij} is the thermal resistance from the metal conductor surface to the surface of the cable in °C-ft/watts, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π) (1ft/12in)(0.3937in/cm)}.

$$\Delta T_{cable} = \frac{Q_{condw}}{3} \cdot R_{ij}$$

ΔT_{ij} is the tempreture drop from the surface of the one metal conductor to the surface of the cable in °C

$\Delta T_{cable} = 0.078$

5) Conductor Temperature

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$\Delta T_{total} = \Delta T_{darmattc} + \Delta T_{cable}$ — ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$\Delta T_{total} = 0.463$

$$T_{conductor} = \left[T_{surface} \cdot \left(\frac{5}{9}\right) - 273 \right] + \Delta T_{total}$$

$T_{conductor}$ is the conductor temperature in °C

$T_{conductor} = 40.553$

E. 12 RHR PIT SUMP PUMP - CABLE No. 1K2-2 (1 - 3/C #10) (file: 1K2_2.mcd)

1) Calculation of the Heat Generated by the Conductors

$I_{cond} := 3.8$ — I_{cond} is the conductor current in amps

$R_{cond} := 0.0013$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 3$ — n_{cond} is the number of conductors in conduit

$$Q_{cond} := (3.41443)\cdot(n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$$

Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$$Q_{cond} = 0.192$$

$$Q_{condw} := (n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$$

Q_{cond} is the heat generated in the conduit in watt/ft

$$Q_{condw} = 0.056$$

2) Total Heat Transferred from the Wrapped Cable

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$$T_{ar} := (T_{am} + 273)\cdot\frac{9}{5}$$

Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft^2-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{darmout} := 3.5$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

a) Calculation of the Heat Transferred by Convection from the Wrapped Cable

$$h_c(t) := 0.27 \cdot \left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)} \right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- ^oF (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w := \pi \cdot \frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$$A_w = 0.916$$

$$Q_c(t) := h_c(t) \cdot A_w \cdot \left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrappd conduit surfece in Btu/hr-ft

b) Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface

$\sigma := 0.1714 \cdot 10^{-8}$ Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w := 0.7$ Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) := \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4\right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface

$$Q_{cr}(t) := Q_c(t) + Q_r(t)$$

Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to the surrounding

$t := 550$

Given

$Q_{cond} = Q_{cr}(t)$

$T_{surface} := \text{Find}(t)$

$T_{surface} = 563.591$

$T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface equal to the heat generated by the cable inside the conduit

$h_c\left(T_{surface}\right) = 0.243$ $Q_r\left(T_{surface}\right) = 0.15$ $Q_c\left(T_{surface}\right) = 0.042$

$Q_{cr}\left(T_{surface}\right) = 0.192$

3) Temperature Drop Through the Darmatt Layer

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft²-°F

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft°F

$K_{darmatt} = 0.065$

$D_{darmout} = 3.5$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{cable} = 0.613$ — D_{cable} is the diameter of the cable in inches

$R_{darmatt} = \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot\ln\left(\frac{D_{darmout}}{D_{cable}}\right)$ — $R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watts

$R_{darmatt} = 4.249$

$\Delta T_{darmatt} = Q_{cond} R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 0.817$

$\Delta T_{darmattc} = \left(\frac{5}{9}\right)\cdot\Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 0.454$

4) Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable

$\rho_i = 500$ — ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watts

$\rho_j = 500$ — ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watts

$\rho_{3j} = 0.5$ — ρ_{3j} is the thermal resistivity of the armor in °C-cm/watts

$t_i = .03$ — t_i is the insulation thickness in inches

$t_j = 0.015$ — t_j is the individual jacket thickness in inches

$t_{oj} = 0.06$ — t_{oj} is the overall jacket thickness in inches

$t_a = 0.025$ — t_a is the armor thickness in inches

$d = 0.116$ — d is the diameter of the conductor metal of one conductor in inches

$d_j = d + 2 \cdot t_j + 2 \cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.206$

$d_i = d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.176$

$d_{3j\phi} = 2.15 \cdot d_j + 2 \cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches

$d_{3j\phi} = 0.563$

$d_{3ju} = d_{3j\phi} - 2 \cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 0.443$

$d_{arm} = d_{3j\phi} + 2 \cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 0.613$

$$R_{ij} = 0.00522 \cdot \left[2 \cdot \left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right) \right) + 3 \cdot \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + 3 \cdot \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right) \right]$$

$R_{ij} = 4.876$ — R_{ij} is the thermal resistance from the metal conductor surface to the surface of the cable in °C-ft/watts, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π) (1ft/12in)(0.3937in/cm)}.

$$\Delta T_{cable} = \frac{Q_{condw}}{3} \cdot R_{ij}$$

ΔT_{ij} is the tempreture drop from the surface of the metal conductor to the surface of the cable in °C

$\Delta T_{cable} = 0.092$

5) **Conductor Temperature**

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$\Delta T_{total} = \Delta T_{darmattc} + \Delta T_{cable}$ — ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$\Delta T_{total} = 0.545$

$$T_{conductor} = \left[T_{surface} \cdot \left(\frac{5}{9}\right) - 273 \right] + \Delta T_{total}$$

$T_{conductor}$ is the conductor temperature in °C

$T_{conductor} = 40.651$

F. 13 CHG PUMP - CABLE No. 1K2-7 (1 - 3/C 1/0) (file: 1K2_7.mcd)

1) Calculation of the Heat Generated by the Conductors

$I_{cond} := 134$ — I_{cond} is the conductor current in amps

$R_{cond} := 0.000128$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 3$ — n_{cond} is the number of conductors in conduit

$Q_{cond} := (3.41443)\cdot(n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{cond} = 23.543$

$Q_{condw} := (n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in watt/ft

$Q_{condw} = 6.895$

2) Total Heat Transferred from the Wrapped Cable

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273)\cdot\frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft^2-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{darmout} := 4.5$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

a) Calculation of the Heat Transferred by Convection from the Wrapped Cable

$$h_c(t) := 0.27\cdot\left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)}\right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- ^oF (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w := \pi\cdot\frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$$A_w = 1.178$$

$$Q_c(t) := h_c(t)\cdot A_w\cdot\left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrappd conduit surfece in Btu/hr-ft

b) Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface

$$\sigma := 0.1714\cdot 10^{-8}$$

Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$$\varepsilon_w := 0.7$$

Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) := \sigma\cdot\varepsilon_w\cdot A_w\cdot\left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4\right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface

$$Q_{cr}(t) := Q_c(t) + Q_r(t)$$

Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to the surrounding

$t := 550$

Given

$$Q_{cond} = Q_{cr}(t)$$

$$T_{surface} := \mathrm{Find}(t)$$

$$T_{surface} = 576.352$$

$T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface equal to the heat generated by the cable inside the conduit

$h_c\left(T_{surface}\right) = 0.655$ $Q_r\left(T_{surface}\right) = 13.555$ $Q_c\left(T_{surface}\right) = 9.988$

$Q_{cr}\left(T_{surface}\right) = 23.543$

3) **Temperature Drop Through the Darmatt Layer**

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft²-°F

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft°F

$K_{darmatt} = 0.065$

$D_{darmout} = 4.5$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{cable} = 1.377$ — D_{cable} is the diameter of the cable in inches

$R_{darmatt} = \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot\ln\left(\frac{D_{darmout}}{D_{cable}}\right)$ — $R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watts

$R_{darmatt} = 2.888$

$\Delta T_{darmatt} = Q_{cond} \cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 68.001$

$\Delta T_{darmattc} = \left(\frac{5}{9}\right)\cdot\Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 37.778$

4) **Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable**

$\rho_i = 500$ — ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watts

$\rho_j = 500$ — ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watts

$\rho_{3j} = 0.5$ — ρ_{3j} is the thermal resistivity of the armor in °C-cm/watts

$t_i = .055$ — t_i is the insulation thickness in inches

$t_j = 0.03$ — t_j is the individual jacket thickness in inches

$t_{oj} = 0.08$ — t_{oj} is the overall jacket thickness in inches

$t_a = 0.025$ — t_a is the armor thickness in inches

$d = 0.373$ — d is the diameter of the conductor metal of one conductor in inches

$d_j = d + 2 \cdot t_j + 2 \cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.543$

$d_i = d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.483$

$d_{3j\phi} = 2.15 \cdot d_j + 2 \cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches

$d_{3j\phi} = 1.327$

$d_{3ju} = d_{3j\phi} - 2 \cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 1.167$

$d_{arm} = d_{3j\phi} + 2 \cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 1.377$

$$R_{ij} = 0.00522 \cdot \left[2 \cdot \left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right) \right) + 3 \cdot \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + 3 \cdot \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right) \right]$$

$R_{ij} = 2.966$ — R_{ij} is the thermal resistance from the metal conductor surface to the surface of the cable in °C-ft/watts, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π) (1ft/12in)(0.3937in/cm)}.

$$\Delta T_{cable} = \frac{Q_{condw}}{3} \cdot R_{ij}$$

$\Delta T_{cable} = 6.817$

ΔT_{ij} is the tempreture drop from the surface of the one metal conductor to the surface of the cable in °C

5) **Conductor Temperature**

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$$\Delta T_{total} = \Delta T_{darmattc} + \Delta T_{cable}$$

$\Delta T_{total} = 44.596$

ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$$T_{conductor} = \left[T_{surface} \cdot \left(\frac{5}{9}\right) - 273 \right] + \Delta T_{total}$$

$T_{conductor}$ is the conductor temperature in °C

$T_{conductor} = 91.791$

G. PANEL 1EMA AND 2EMA FEEDERS - CABLE No. 1CA-1228 & 2CA-601 (2/C - #6)

1) Calculation of the Heat Generated in the Conduit

(file:EMA_12.MCD)

$I_{1ca} := 14.5$ — I_{1ca} is the cable 1CA-1228 current in amps

$I_{2ca} := 14$ — I_{2ca} is the cable 2CA-601 current in amps

$R_{cond} := 0.000513$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 2$ — n_{cond} is the number of conductors in conduit

$Q_{1ca} := (3.41443) \cdot (n_{cond}) \cdot (I_{1ca}^2) \cdot (R_{cond})$ — Q_{1ca} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{1ca} = 0.737$

$Q_{2ca} := (3.41443) \cdot (n_{cond}) \cdot (I_{1ca}^2) \cdot (R_{cond})$ — Q_{2ca} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{2ca} = 0.737$

$Q_{total} := Q_{1ca} + Q_{2ca}$ — Q_{total} is the total heat generated in the conduit in Btu/hr-ft

$Q_{total} = 1.473$

$Q_{1caw} := (n_{cond}) \cdot (I_{1ca})^2 \cdot (R_{cond})$ — Q_{1caw} is the heat generated in the conduit in watt/ft

$Q_{1caw} = 0.216$

$Q_{2caw} := (n_{cond}) \cdot (I_{2ca})^2 \cdot (R_{cond})$ — Q_{1caw} is the heat generated in the conduit in watt/ft

$Q_{2caw} = 0.201$

$Q_{totalw} := Q_{1caw} + Q_{2caw}$ — Q_{totalw} is the total heat generated in the conduit in watt/ft

$Q_{totalw} = 0.417$

2) Total Heat Transferred from the Wrapped Conduit

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273) \cdot \frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft^2-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{condout} := 3.5$ — $D_{condout}$ is the outside diameter of the conduit in inches

$D_{darmout} := D_{condout} + 2 \cdot t_{darmatt}$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmout} = 6$

a) <u>Calculation of the Heat Transferred by Convection from the Wrapped Conduit</u>

$$h_c(t) := 0.27 \cdot \left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)} \right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- °F (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w := \pi \cdot \frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$A_w = 1.571$

$$Q_c(t) := h_c(t) \cdot A_w \cdot \left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrappd conduit surfece in Btu/hr-ft

b) <u>Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface</u>

$\sigma := 0.1714 \cdot 10^{-8}$ — Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w := 0.7$ — Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) := \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4 \right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) **Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface**

$Q_{cr}(t) := Q_c(t) + Q_r(t)$ — Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to the surrounding

$t := 550$

Given

$Q_{total} = Q_{cr}(t)$

$T_{surface} := \text{Find}(t)$ — $T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface equal to the heat generated by the cable inside the conduit

$T_{surface} = 564.205$

$h_c(T_{surface}) = 0.304$ $Q_r(T_{surface}) = 1.088$ $Q_c(T_{surface}) = 0.385$

$Q_{cr}(T_{surface}) = 1.473$

3) **Temperature Drop Through the Darmatt Layer**

$K_{darmattin} := 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft^2-°F

$K_{darmatt} := \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft°F

$K_{darmatt} = 0.065$

$D_{darmout} := 6$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmin} := D_{condout}$ — D_{darmin} is the inside diameter of the Darmatt in inches or the outside diameter of the conduit

$R_{darmatt} := \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot\ln\left(\frac{D_{darmout}}{D_{darmin}}\right)$ — $R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watts

$R_{darmatt} = 1.315$

$\Delta T_{darmatt} := Q_{total} \cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 1.937$

$\Delta T_{darmattc} := \left(\frac{5}{9}\right)\cdot\Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 1.076$

4) Temperature Drop Through the Conduit Wall

$D_{conduit} = 3.5$ — $D_{conduit}$ is the nominal diameter of the conduit in inches

$D_{condout} = 3.5$ — $D_{condout}$ is the outside diameter of the conduit in inches

$t_{cond} = 0.215$ — t_{cond} is the conduit wall thickness in inches

$D_{condin} = D_{condout} - 2 \cdot t_{cond}$ — D_{condin} is the inside diameter of the conduit in inches

$D_{condin} = 3.07$

$\rho_{cond} = 2.08$ — ρ_{cond} is the thermal resistivity of the conduit material in °C-cm/watt

$$R_{cond} = 0.00522 \cdot \rho_{cond} \cdot \ln\left(\frac{D_{condout}}{D_{condin}}\right)$$

$R_{cond} = 0.001$

R_{cond} is the thermal resistance of the conduit in °C-ft/watt, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π)(1ft/12in)(0.3937in/cm)}

$\Delta T_{conduit} = Q_{totalw} \cdot R_{cond}$ — $\Delta T_{conduit}$ is the tempreture drop through the conduit in °C

$\Delta T_{conduit} = 5.932 \cdot 10^{-4}$

5) Calculation of the Temperature drop through the Air Space Between the Cable Surface and the Inside Surface of the Conduit

$A' = 3.2$

$B' = 0.19$

A` & B` are constants used to determine the thermal resistance between the cable surface and the inside surface of the conduit

$D_{cable} = 1.49$ — D_{cable} is the diameter of the group of conductors inside the conduit in inches determined in section 6 (two cable 2/C #6)

$$R_{sc} = \frac{A'}{D_{cable} + B'}$$

R_{sc} is the thermal resistance of the air gap between the cable surface and the inside surface of the conduit in °C-ft/watt

$R_{sc} = 1.905$

$\Delta T_{air} = Q_{totalw} \cdot R_{sc}$ — ΔT_{air} is the temperature drop in the air space between the cable surface and the inside surface of the conduit in °C

$\Delta T_{air} = 0.794$

6) **Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable**

$\rho_i = 500$ — ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watts

$\rho_j = 500$ — ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watts

$\rho_{3j} = 0.5$ — ρ_{3j} is the thermal resistivity of the armor in °C-cm/watts

$t_i = .045$ — t_i is the insulation thickness in inches

$t_j = 0.025$ — t_j is the individual jacket thickness in inches

$t_{oj} = 0.08$ — t_{oj} is the overall jacket thickness in inches

$t_a = 0.025$ — t_a is the armor thickness in inches

$d = 0.184$ — d is the diameter of the conductor metal of one conductor in inches

$d_j = d + 2 \cdot t_j + 2 \cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.324$

$d_i = d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.274$

$d_{3j\phi} = 1.65 \cdot d_j + 2 \cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches for two conductors

$d_{3j\phi} = 0.695$

$d_{3ju} = d_{3j\phi} - 2 \cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 0.535$

$d_{arm} = d_{3j\phi} + 2 \cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 0.745$

$$R_{ij} = 0.00522 \cdot \left[\left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right) \right) + \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right) \right]$$

$R_{ij} = 2.16$ — R_{ij} is the thermal resistance from the metal conductor surface to the surface of the cable in °C-ft/watts, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π) (1ft/12in)(0.3937in/cm)}.

$\Delta T_{1ca} = Q_{1caw} \cdot R_{ij}$

ΔT_{1ca} is the tempreture drop from the surface of the one metal conductor to the surface of the cable in °C (cable 1CA-1228)

$\Delta T_{1ca} = 0.466$

$\Delta T_{2ca} = Q_{2caw} \cdot R_{ij}$

ΔT_{2ca} is the tempreture drop from the surface of the one metal conductor to the surface of the cable in °C (cable 2CA-601)

$\Delta T_{2ca} = 0.434$

7) Conductor Temperature

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$\Delta T_{1total} = \Delta T_{darmattc} + \Delta T_{conduit} + \Delta T_{air} + \Delta T_{1ca}$

ΔT_{1total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$\Delta T_{1total} = 2.336$

$T_{conductor\_1ca} = \left[T_{surface} \cdot \left(\frac{5}{9} \right) - 273 \right] + \Delta T_{1total}$

$T_{conductor\_1ca}$ is the conductor temperature in °C for cable 1CA_1228

$T_{conductor\_1ca} = 42.784$

$\Delta T_{2total} = \Delta T_{darmattc} + \Delta T_{conduit} + \Delta T_{air} + \Delta T_{2ca}$

ΔT_{2total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$\Delta T_{2total} = 2.305$

$T_{conductor\_2ca} = \left[T_{surface} \cdot \left(\frac{5}{9} \right) - 273 \right] + \Delta T_{2total}$

$T_{conductor\_1ca}$ is the conductor temperature in °C for cable 1CA_601

$T_{conductor\_2ca} = 42.752$

H. PANEL 1EMA AND 2EMA FEEDERS - CABLE No. 1CA-1228 & 2CA-601 (2/C - #6) DROP

(file:EMA_12D.MCD)

1) Calculation of the Heat Generated in the Conduit

$I_{1ca} := 14.5$ — I_{1ca} is the cable 1CA-1228 current in amps

$I_{2ca} := 14$ — I_{2ca} is the cable 2CA-601 current in amps

$R_{cond} := 0.000513$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 2$ — n_{cond} is the number of conductors in conduit

$Q_{1ca} := (3.41443)\cdot(n_{cond})\cdot(I_{1ca}^2)\cdot(R_{cond})$ — Q_{1ca} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{1ca} = 0.737$

$Q_{2ca} := (3.41443)\cdot(n_{cond})\cdot(I_{1ca}^2)\cdot(R_{cond})$ — Q_{2ca} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{2ca} = 0.737$

$Q_{total} := Q_{1ca} + Q_{2ca}$ — Q_{total} is the total heat generated in the conduit in Btu/hr-ft

$Q_{total} = 1.473$

$Q_{1caw} := (n_{cond})\cdot(I_{1ca})^2\cdot R_{cond}$ — Q_{1caw} is the heat generated in the conduit in watt/ft

$Q_{1caw} = 0.216$

$Q_{2caw} := (n_{cond})\cdot(I_{2ca})^2\cdot R_{cond}$ — Q_{1caw} is the heat generated in the conduit in watt/ft

$Q_{2caw} = 0.201$

$Q_{totalw} := Q_{1caw} + Q_{2caw}$ — Q_{totalw} is the total heat generated in the conduit in watt/ft

$Q_{totalw} = 0.417$

2) Total Heat Transferred from the Wrapped Conduit

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273)\cdot\frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft^2-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} = 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} = 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{condout} = 3.5$ — $D_{condout}$ is the outside diameter of the conduit in inches

$D_{darmout} = D_{condout} + 2 \cdot t_{darmatt}$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmout} = 6$

a) **Calculation of the Heat Transferred by Convection from the Wrapped Conduit**

$$h_c(t) = 0.27 \cdot \left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)}\right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- °F (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w = \pi \cdot \frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$A_w = 1.571$

$$Q_c(t) = h_c(t) \cdot A_w \cdot \left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrapped conduit surfece in Btu/hr-ft

b) **Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface**

$\sigma = 0.1714 \cdot 10^{-8}$ — Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w = 0.7$ — Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) = \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4\right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) **Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface**

$Q_{cr}(t) := Q_c(t) + Q_r(t)$ — Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to the surrounding

$t := 550$

Given

$Q_{total} = Q_{cr}(t)$

$T_{surface} := \text{Find}(t)$ — $T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface equal to the heat generated by the cable inside the conduit

$T_{surface} = 564.205$

$h_c(T_{surface}) = 0.304$ $\quad Q_r(T_{surface}) = 1.088$ $\quad Q_c(T_{surface}) = 0.385$

$Q_{cr}(T_{surface}) = 1.473$

3) **Temperature Drop Through the Darmatt Layer**

$K_{darmattin} := 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft^2-°F

$K_{darmatt} := \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft°F

$K_{darmatt} = 0.065$

$D_{darmout} := 6$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{cable} := 1.49$ — D_{cable} is the diameter of the group of conductors inside the conduit in inches determined in section 6 (two cable 2/C, #6)

$D_{darmin} := D_{cable}$ — D_{darmin} is the inside diameter of the Darmatt in inches or the outside diameter of the conduit

$$R_{darmatt} := \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot\ln\left(\frac{D_{darmout}}{D_{darmin}}\right)$$

$R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watts

$R_{darmatt} = 3.398$

$\Delta T_{darmatt} := Q_{total}\cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 5.005$

$\Delta T_{darmattc} := \left(\frac{5}{9}\right)\cdot\Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 2.781$

4) Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable

$\rho_i = 500$ — ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watts

$\rho_j = 500$ — ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watts

$\rho_{3j} = 0.5$ — ρ_{3j} is the thermal resistivity of the armor in °C-cm/watts

$t_i = .045$ — t_i is the insulation thickness in inches

$t_j = 0.025$ — t_j is the individual jacket thickness in inches

$t_{oj} = 0.08$ — t_{oj} is the overall jacket thickness in inches

$t_a = 0.025$ — t_a is the armor thickness in inches

$d = 0.184$ — d is the diameter of the conductor metal of one conductor in inches

$d_j = d + 2 \cdot t_j + 2 \cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.324$

$d_i = d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.274$

$d_{3j\phi} = 1.65 \cdot d_j + 2 \cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches for two conductors

$d_{3j\phi} = 0.695$

$d_{3ju} = d_{3j\phi} - 2 \cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 0.535$

$d_{arm} := d_{3j\phi} + 2 \cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 0.745$

$$R_{ij} := 0.00522 \cdot \left[\left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right) \right) + \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right) \right]$$

$R_{ij} = 2.16$ — R_{ij} is the thermal resistance from the metal conductor surface to the surface of the cable in °C-ft/watts, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π) (1ft/12in)(0.3937in/cm)}.

$\Delta T_{1ca} := Q_{1caw} \cdot R_{ij}$ — ΔT_{1ca} is the tempreture drop from the surface of the one metal conductor to the surface of the cable in °C (cable 1CA-1228)

$\Delta T_{1ca} = 0.466$

$\Delta T_{2ca} := Q_{2caw} \cdot R_{ij}$ — ΔT_{2ca} is the tempreture drop from the surface of the one metal conductor to the surface of the cable in °C (cable 2CA-601)

$\Delta T_{2ca} = 0.434$

5) <u>Conductor Temperature</u>

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$\Delta T_{1total} := \Delta T_{darmattc} + \Delta T_{1ca}$ — ΔT_{1total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$\Delta T_{1total} = 3.247$

$T_{conductor\_1ca} := \left[T_{surface} \cdot \left(\frac{5}{9}\right) - 273 \right] + \Delta T_{1total}$ — $T_{conductor\_1ca}$ is the conductor temperature in °C for cable 1CA_1228

$T_{conductor\_1ca} = 43.694$

$\Delta T_{2total} := \Delta T_{darmattc} + \Delta T_{2ca}$ — ΔT_{2total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$\Delta T_{2total} = 3.215$

$T_{conductor\_2ca} := \left[T_{surface} \cdot \left(\frac{5}{9}\right) - 273 \right] + \Delta T_{2total}$ — $T_{conductor\_1ca}$ is the conductor temperature in °C for cable 1CA_601

$T_{conductor\_2ca} = 43.663$

I. **PANEL 135 FEEDER - CABLE No. 1K2-18 (1-3/C #2) (Conduit)** (file: 1K2_18C.mcd)

1) **Calculation of the Heat Generated in the Conduit**

$I_{cond} := 24$ — I_{cond} is the conductor current in amps

$R_{cond} := 0.000203$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 3$ — n_{cond} is the number of cables in conduit

$Q_{cond} := (3.41443)\cdot(n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{cond} = 1.198$

$Q_{condw} := (n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in watt/ft

$Q_{condw} = 0.351$

2) **Total Heat Transferred from the Wrapped Conduit**

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273)\cdot\frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft²-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{condout} := 2.375$ — $D_{condout}$ is the outside diameter of the conduit in inches

$D_{darmout} := D_{condout} + 2\cdot t_{darmatt}$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmout} = 4.875$

a) **Calculation of the Heat Transferred by Convection from the Wrapped Conduit**

$$h_c(t) = 0.27 \cdot \left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)}\right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- ^oF (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w = \pi \cdot \frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$$A_w = 1.276$$

$$Q_c(t) = h_c(t) \cdot A_w \cdot \left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrappd conduit surfece in Btu/hr-ft

b) **Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface**

$\sigma = 0.1714 \cdot 10^{-8}$ Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w = 0.7$ Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) = \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4\right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) **Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface**

$$Q_{cr}(t) = Q_c(t) + Q_r(t)$$

Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to its surroundings

$t = 550$

Given

$Q_{cond} = Q_{cr}(t)$

$T_{surface} = \text{Find}(t)$

$T_{surface} = 564.196$

$T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface is equal to the heat generated by the cable inside the conduit

$h_c\left(T_{surface}\right) = 0.319$ $Q_r\left(T_{surface}\right) = 0.873$ $Q_c\left(T_{surface}\right) = 0.324$

$Q_{cr}\left(T_{surface}\right) = 1.198$

3) Temperature Drop Through the Darmatt Layer

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft^2-^{o}F

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft^{o}F

$K_{darmatt} = 0.065$

$D_{darmout} = 4.875$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmin} = D_{condout}$ — D_{darmin} is the inside diameter of the Darmatt in inches or the outside diameter of the conduit

$R_{darmatt} = \left(\frac{1}{2 \cdot \pi}\right) \cdot \left(\frac{1}{K_{darmatt}}\right) \cdot \ln\left(\frac{D_{darmout}}{D_{darmin}}\right)$ — $R_{darmatt}$ is the thermal resistance of the Darmatt layer in ^{o}R-ft/watts

$R_{darmatt} = 1.754$

$\Delta T_{darmatt} = Q_{cond} \cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 2.101$

$\Delta T_{darmattc} = \left(\frac{5}{9}\right) \cdot \Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in ^{o}C

$\Delta T_{darmattc} = 1.167$

4) Temperature Drop Through the Conduit Wall

$D_{conduit} = 2.083$ — $D_{conduit}$ is the nominal diameter of the conduit in inches

$D_{condout} = 2.375$ — $D_{condout}$ is the outside diameter of the conduit in inches

$t_{cond} = 0.133$ — t_{cond} is the conduit wall thickness in inches

$D_{condin} = D_{condout} - 2 \cdot t_{cond}$ — D_{condin} is the inside diameter of the conduit in inches

$D_{condin} = 2.109$

$\rho_{cond} = 2.08$ — ρ_{cond} is the thermal resistivity of the conduit material in ^{o}C-cm/watt

$R_{cond} = 0.00522 \cdot \rho_{cond} \ln\left(\frac{D_{condout}}{D_{condin}}\right)$

$R_{cond} = 0.001$

R_{cond} is the thermal resistance of the conduit in °C-ft/watt, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π)(1ft/12in)(0.3937in/cm)}

$\Delta T_{conduit} = Q_{condw} \cdot R_{cond}$

$\Delta T_{conduit}$ is the tempreture drop through the conduit in °C

$\Delta T_{conduit} = 4.524 \cdot 10^{-4}$

5) Calculation of the Temperature drop through the Air Space Between the Cable Surface and the Inside Surface of the Conduit

$A' = 3.2$

$B' = 0.19$

A' & B' are constants used to determine the thermal resistance between the cable surface and the inside surface of the conduit

$D_{cable} = 1.139$

D_{cable} is the diameter of the cable in inches

$R_{sc} = \frac{A'}{D_{cable} + B'}$

R_{sc} is the thermal resistance of the air gap between the cable surface and the inside surface of the conduit in °C-ft/watt

$R_{sc} = 2.408$

$\Delta T_{air} = Q_{condw} \cdot R_{sc}$

ΔT_{air} is the temperature drop in the air space between the cable surface and the inside surface of the conduit in °C

$\Delta T_{air} = 0.845$

6) Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable

$\rho_i = 500$

ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watt

$\rho_j = 500$

ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watt

$\rho_{3j} = 0.5$

ρ_{3j} is the thermal resistivity of the armor in °C-cm/watt

$t_i = .045$ — t_i is the insulation thickness in inches

$t_j = 0.025$ — t_j is the individual jacket thickness in inches

$t_{oj} = 0.08$ — t_{oj} is the overall jacket thickness in inches

$t_a = 0.025$ — t_a is the armor thickness

$d = 0.292$ — d is the diameter of the conductor metal of one conductor in inches

$d_j = d + 2 \cdot t_j + 2 \cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.432$

$d_i = d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.382$

$d_{3j\phi} = 2.15 \cdot d_j + 2 \cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches

$d_{3j\phi} = 1.089$

$d_{3ju} = d_{3j\phi} - 2 \cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 0.929$

$d_{arm} = d_{3j\phi} + 2 \cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 1.139$

$$R_{ij} = 0.00522 \cdot \left[2 \cdot \left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right) \right) + 3 \cdot \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + 3 \cdot \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right) \right]$$

$R_{ij} = 3.289$ — R_{ij} is the therma resistance from the metal conductor surface to the surface of the cable in °C-ft/watt, 0.00522 is a conersion to feet from centimenters and the combination of constants {(1/2π)(1ft/12in)(0.3937 in/cm)}

$$\Delta T_{cable} = \frac{Q_{condw}}{3} \cdot R_{ij}$$

ΔT_{ij} is the tempreture drop from the surface of the metal conductor to the surface of the cable in °C

$\Delta T_{cable} = 0.385$

7) Conductor Temperature

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$$\Delta T_{total} = \Delta T_{darmatte} + \Delta T_{conduit} + \Delta T_{air} + \Delta T_{cable}$$

ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$$\Delta T_{total} = 2.397$$

$$T_{conductor} = \left[T_{surface} \cdot \left(\frac{5}{9}\right) - 273\right] + \Delta T_{total}$$

$T_{conductor}$ is the conductor tempreture in °C

$$T_{conductor} = 42.839$$

J. MV-32267- CABLE No. 1K2-20 (1-3/C #10) (Conduit) (file: 1K2_20C.mcd)

1) Calculation of the Heat Generated in the Conduit

$I_{cond} := 3.5$ — I_{cond} is the conductor current in amps

$R_{cond} := 0.0013$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 3$ — n_{cond} is the number of cables in conduit

$Q_{cond} := (3.41443) \cdot (n_{cond}) \cdot (I_{cond})^2 \cdot (R_{cond})$ — Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{cond} = 0.163$

$Q_{condw} := (n_{cond}) \cdot (I_{cond})^2 \cdot (R_{cond})$ — Q_{cond} is the heat generated in the conduit in watt/ft

$Q_{condw} = 0.048$

2) Total Heat Transferred from the Wrapped Conduit

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273) \cdot \frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft^2-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{condout} := 1.660$ — $D_{condout}$ is the outside diameter of the conduit in inches

$D_{darmout} := D_{condout} + 2 \cdot t_{darmatt}$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmout} = 4.16$

a) **Calculation of the Heat Transferred by Convection from the Wrapped Conduit**

$$h_c(t) := 0.27\cdot\left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)}\right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2-°F (Ref. XII.D, Table 7-4, Horizontal Cylinders)

$$A_w := \pi\cdot\frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$A_w = 1.089$

$$Q_c(t) := h_c(t)\cdot A_w\cdot\left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrappd conduit surfece in Btu/hr-ft

b) **Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface**

$\sigma := 0.1714\cdot 10^{-8}$ Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w := 0.7$ Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) := \sigma\cdot\varepsilon_w\cdot A_w\cdot\left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4\right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) **Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface**

$$Q_{cr}(t) := Q_c(t) + Q_r(t)$$

Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to the surrounding

$t := 550$

Given

$Q_{cond} = Q_{cr}(t)$

$T_{surface} := \text{Find}(t)$

$T_{surface} = 563.54$

$T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface is equal to the heat generated by the cable inside the conduit

$h_c\left(T_{surface}\right) = 0.215$ $Q_r\left(T_{surface}\right) = 0.13$ $Q_c\left(T_{surface}\right) = 0.033$

$Q_{cr}\left(T_{surface}\right) = 0.163$

3) Temperature Drop Through the Darmatt Layer

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft^2-°F

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft°F

$K_{darmatt} = 0.065$

$D_{darmout} = 4.16$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmin} = D_{condout}$ — D_{darmin} is the inside diameter of the Darmatt in inches or the outside diameter of the conduit

$R_{darmatt} = \left(\frac{1}{2 \cdot \pi}\right) \cdot \left(\frac{1}{K_{darmatt}}\right) \cdot \ln\left(\frac{D_{darmout}}{D_{darmin}}\right)$ — $R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watts

$R_{darmatt} = 2.241$

$\Delta T_{darmatt} = Q_{cond} \cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 0.366$

$\Delta T_{darmattc} = \left(\frac{5}{9}\right) \cdot \Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 0.203$

4) Temperature Drop Through the Conduit Wall

$D_{conduit} = 1.394$ — $D_{conduit}$ is the nominal diameter of the conduit in inches

$D_{condout} = 1.66$ — $D_{condout}$ is the outside diameter of the conduit in inches

$t_{cond} = 0.133$ — t_{cond} is the conduit wall thickness in inches

$D_{condin} = D_{condout} - 2 \cdot t_{cond}$ — D_{condin} is the inside diameter of the conduit in inches

$D_{condin} = 1.394$

$\rho_{cond} = 2.08$ — ρ_{cond} is the thermal resistivity of the conduit material in °C-cm/watt

$R_{cond} = 0.00522 \cdot \rho_{cond} \cdot \ln\left(\frac{D_{condout}}{D_{condin}}\right)$

$R_{cond} = 0.002$

R_{cond} is the thermal resistance of the conduit in °C-ft/watt, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π)(1ft/12in)(0.3937in/cm)}

$\Delta T_{conduit} = Q_{condw} \cdot R_{cond}$

$\Delta T_{conduit}$ is the temperature drop through the conduit in °C

$\Delta T_{conduit} = 9.059 \cdot 10^{-5}$

5) <u>Calculation of the Temperature drop through the Air Space Between the Cable Surface and the Inside Surface of the Conduit</u>

$A' = 3.2$

$B' = 0.19$

A` & B` are constants used to determine the thermal resistance between the cable surface and the inside surface of the conduit

$D_{cable} = 0.613$

D_{cable} is the diameter of the cable in inches

$R_{sc} = \frac{A'}{D_{cable} + B'}$

R_{sc} is the thermal resistance of the air gap between the cable surface and the inside surface of the conduit in °C-ft/watt

$R_{sc} = 3.985$

$\Delta T_{air} = Q_{condw} \cdot R_{sc}$

ΔT_{air} is the temperature drop in the air space between the cable surface and the inside surface of the conduit in °C

$\Delta T_{air} = 0.19$

6) <u>Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable</u>

$\rho_i = 500$

ρ_i is the thermal resistivity of the insulation surrounding one of the conductors in °C-cm/watts

$\rho_j = 500$

ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watts

$\rho_{3j} = 0.5$

ρ_{3j} is the thermal resistivity of the armor in °C-cm/watt

$t_i := .03$ — t_i is the insulation thickness in inches

$t_j := 0.015$ — t_j is the individual jacket thickness in inches

$t_{oj} := 0.06$ — t_{oj} is the overall jacket thickness in inches

$t_a := 0.025$ — t_a is the armor thickness

$d := 0.116$ — d is the diameter of the conductor metal of one conductor in inches

$d_j := d + 2 \cdot t_j + 2 \cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.206$

$d_i := d + 2 \cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.176$

$d_{3j\phi} := 2.15 \cdot d_j + 2 \cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches

$d_{3j\phi} = 0.563$

$d_{3ju} := d_{3j\phi} - 2 \cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 0.443$

$d_{arm} := d_{3j\phi} + 2 \cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 0.613$

$$R_{ij} := 0.00522 \cdot \left[2 \cdot \left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right) \right) + 3 \cdot \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + 3 \cdot \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right) \right]$$

$R_{ij} = 4.876$ — R_{ij} is the therma resistance from the metal conductor surface to the surface of the cable in °C-ft/watt, 0.00522 is a conersion to feet from centimenters and the combination of constants {(1/2π)(1ft/12in)(0.3937 in/cm)}

$$\Delta T_{cable} := \frac{Q_{condw}}{3} \cdot R_{ij}$$

ΔT_{ij} is the tempreture drop from the surface of the metal conductor to the surface of the cable in °C

$\Delta T_{cable} = 0.078$

7) <u>Conductor Temperature</u>

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$$\Delta T_{total} = \Delta T_{darmattc} - \Delta T_{conduit} + \Delta T_{air} + \Delta T_{cable}$$

ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$$\Delta T_{total} = 0.471$$

$$T_{conductor} = \left[T_{surface} \cdot \left(\frac{5}{9} \right) - 273 \right] + \Delta T_{total}$$

$T_{conductor}$ is the conductor temperature in ^{o}C

$$T_{conductor} = 40.549$$

K. 12 SI PUMP FEEDER - CABLE No. 16407-1 (1-3/C #2, 5 kV) (file: 16407-1.mcd)

1) Calculation of the Heat Generated in the Conduit

$I_{cond} := 100$ — I_{cond} is the conductor current in amps

$R_{cond} := 0.000203$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 3$ — n_{cond} is the number of cables in conduit

$Q_{cond} := (3.41443)\cdot(n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{cond} = 20.794$

$Q_{condw} := (n_{cond})\cdot(I_{cond})^2\cdot(R_{cond})$ — Q_{cond} is the heat generated in the conduit in watt/ft

$Q_{condw} = 6.09$

2) Total Heat Transferred from the Wrapped Conduit

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273)\cdot\frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft²-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{condout} := 4.500$ — $D_{condout}$ is the outside diameter of the conduit in inches

$D_{darmout} := D_{condout} + 2\cdot t_{darmatt}$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmout} = 7$

a) Calculation of the Heat Transferred by Convection from the Wrapped Conduit

$$h_c(t) := 0.27 \cdot \left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)}\right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- ^oF (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w := \pi \cdot \frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$$A_w = 1.833$$

$$Q_c(t) := h_c(t) \cdot A_w \cdot \left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrappd conduit surfece in Btu/hr-ft

b) Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface

$\sigma := 0.1714 \cdot 10^{-8}$ Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w := 0.7$ Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) := \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4\right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface

$$Q_{cr}(t) := Q_c(t) + Q_r(t)$$

Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to its surroundings

$t := 550$

Given

$Q_{cond} = Q_{cr}(t)$

$T_{surface} := \text{Find}(t)$

$T_{surface} = 571.514$

$T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface is equal to the heat generated by the cable inside the conduit

$h_c\left(T_{surface}\right) = 0.521$ $Q_r\left(T_{surface}\right) = 13.04$ $Q_c\left(T_{surface}\right) = 7.753$

$Q_{cr}\left(T_{surface}\right) = 20.794$

3) Temperature Drop Through the Darmatt Layer

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft^2-°F

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft°F

$K_{darmatt} = 0.065$

$D_{darmout} = 7$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmin} = D_{condout}$ — D_{darmin} is the inside diameter of the Darmatt in inches or the outside diameter of the conduit

$$R_{darmatt} = \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot\ln\left(\frac{D_{darmout}}{D_{darmin}}\right)$$

$R_{darmatt}$ is the thermal resistance of the Darmatt layer in °R-ft/watts

$R_{darmatt} = 1.078$

$\Delta T_{darmatt} = Q_{cond}\cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 22.41$

$\Delta T_{darmattc} = \left(\frac{5}{9}\right)\cdot\Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in °C

$\Delta T_{darmattc} = 12.45$

4) Temperature Drop Through the Conduit Wall

$D_{conduit} = 4.00$ — $D_{conduit}$ is the nominal diameter of the conduit in inches

$D_{condout} = 4.5$ — $D_{condout}$ is the outside diameter of the conduit in inches

$t_{cond} = 0.225$ — t_{cond} is the conduit wall thickness in inches

$D_{condin} = D_{condout} - 2\cdot t_{cond}$ — D_{condin} is the inside diameter of the conduit in inches

$D_{condin} = 4.05$

$\rho_{cond} = 2.08$ — ρ_{cond} is the thermal resistivity of the conduit material in °C-cm/watt

$R_{cond} = 0.00522 \cdot \rho_{cond} \cdot \ln\left(\frac{D_{condout}}{D_{condin}}\right)$

$R_{cond} = 0.001$

R_{cond} is the thermal resistance of the conduit in °C-ft/watt, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π)(1ft/12in)(0.3937in/cm)}

$\Delta T_{conduit} = Q_{condw} \cdot R_{cond}$

$\Delta T_{conduit}$ is the tempreture drop through the conduit in °C

$\Delta T_{conduit} = 0.007$

5) Calculation of the Temperature drop through the Air Space Between the Cable Surface and the [illegible]e Surface of the Conduit

$A' = 3.2$

$B' = 0.19$

A` & B` are constants used to determine the thermal resistance between the cable surface and the inside surface of the conduit

$D_{cable} = 1.84$

D_{cable} is the diameter of the cable in inches

$R_{sc} = \frac{A'}{D_{cable} + B'}$

R_{sc} is the thermal resistance of the air gap between the cable surface and the inside surface of the conduit in °C-ft/watt

$R_{sc} = 1.576$

$\Delta T_{air} = Q_{condw} \cdot R_{sc}$

ΔT_{air} is the temperature drop in the air space between the cable surface and the inside surface of the conduit in °C

$\Delta T_{air} = 9.6$

6) Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable

$\rho_i = 500$

ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watt

$\rho_j = 500$

ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watt

$\rho_{3j} = 0.5$

ρ_{3j} is the thermal resistivity of the armor in °C-cm/watt

$d = 0.296$ — d is the diameter of the conductor metal of one conductor in inches

$t_i = \frac{8}{64}$ — t_i is the insulation thickness in inches

$t_j = \frac{5}{64}$ — t_j is the individual jacket thickness in inches

t_{oj} is the overall jacket thickness in inches

$$t_{oj} = \frac{1.84 - 2\cdot 0.025 - 2.15\cdot\left[d + 2\cdot\left(t_i + t_j\right)\right]}{2} \qquad t_{oj} = 0.14$$

$t_a = 0.025$ — t_a is the armor thickness

$d_j = d + 2\cdot t_j + 2\cdot t_i$ — d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.702$

$d_i = d + 2\cdot t_i$ — d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.546$

$d_{3j\phi} = 2.15\cdot d_j + 2\cdot t_{oj}$ — $d_{3j\phi}$ is the diameter over the overall jacket in inches

$d_{3j\phi} = 1.79$

$d_{3ju} = d_{3j\phi} - 2\cdot t_{oj}$ — d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 1.51$

$d_{arm} = d_{3j\phi} + 2\cdot t_a$ — d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 1.84$

$$R_{ij} = 0.00522\cdot\left[2\cdot\left(\rho_i\cdot\ln\left(\frac{d_i}{d}\right) + \rho_j\cdot\ln\left(\frac{d_j}{d_i}\right)\right) + 3\cdot\rho_j\cdot\ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + 3\cdot\rho_{3j}\cdot\ln\left(\frac{d_{arm}}{d_{3j\phi}}\right)\right]$$

$R_{ij} = 5.843$ — R_{ij} is the therma resistance from the metal conductor surface to the surface of the cable in °C-ft/watt, 0.00522 is a conersion to feet from centimenters and the combination of constants {(1/2π)(1ft/12in)(0.3937 in/cm)}

$$\Delta T_{cable} = \frac{Q_{condw}}{3}\cdot R_{ij}$$

ΔT_{ij} is the tempreture drop from the surface of the metal conductor to the surface of the cable in °C

$\Delta T_{cable} = 11.861$

7) **Conductor Temperature**

The conductor temperature inside the conduit is equal to the temperature drop througn the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$$\Delta T_{total} = \Delta T_{darmattc} + \Delta T_{conduit} + \Delta T_{air} + \Delta T_{cable}$$

ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$$\Delta T_{total} = 33.917$$

$$T_{conductor} = \left[T_{surface} \cdot \left(\frac{5}{9} \right) - 273 \right] + \Delta T_{total}$$

$T_{conductor}$ is the conductor tempreture in °C

$$T_{conductor} = 78.425$$

L. 12 SI PUMP FEEDER - CABLE No. 15406-1 (1-3/C #4/0, 5 kV) (file: 15406-1.mcd)

1) Calculation of the Heat Generated in the Conduit

$I_{cond} := 102$ — I_{cond} is the conductor current in amps

$R_{cond} := 0.00639 \cdot 10^{-2}$ — R_{cond} is the conductor resistance at 90 °C in ohms/ft

$n_{cond} := 3$ — n_{cond} is the number of cables in conduit

$Q_{cond} := (3.41443) \cdot (n_{cond}) \cdot (I_{cond})^2 \cdot (R_{cond})$ — Q_{cond} is the heat generated in the conduit in Btu/hr-ft, 3.41443 is the conversion factor from watts/ft to Btu/hr-ft

$Q_{cond} = 6.81$

$Q_{condw} := (n_{cond}) \cdot (I_{cond})^2 \cdot (R_{cond})$ — Q_{cond} is the heat generated in the conduit in watt/ft

$Q_{condw} = 1.994$

2) Total Heat Transferred from the Wrapped Conduit

$T_{am} := 40$ — T_{am} is the ambient air temperature in °C

$T_{ar} := (T_{am} + 273) \cdot \frac{9}{5}$ — Conversion of temperature to °R in order to calculate the heat transfer coefficient in Btu/hr-ft^2-°F

$T_{ar} = 563.4$ — T_{ar} is the ambient air temperature in degrees Rankine

$T_{sw}(t) := t$ — T_{sw} is the surface temperature of the wrapped conduit, this value is iterated until the heat dissipated by Darmatt surface is equal to the heat generated inside the conduit

$T_{cr} := 90$ — T_{cr} is the conductor rated temperature in degrees Celsius

$t_{darmatt} := 1.25$ — $t_{darmatt}$ is the thickness of the Darmatt layer in inches

$D_{condout} := 3.500$ — $D_{condout}$ is the outside diameter of the conduit in inches

$D_{darmout} := D_{condout} + 2 \cdot t_{darmatt}$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmout} = 6$

a) Calculation of the Heat Transferred by Convection from the Wrapped Conduit

$$h_c(t) := 0.27 \cdot \left[\frac{\left(T_{sw}(t) - T_{ar}\right)}{\left(\frac{D_{darmout}}{12}\right)} \right]^{0.25}$$

h_c is the heat transfer coefficient of the wrapped conduit in Btu/hr-ft^2- ^{o}F (Ref. XII.D, Table 7-4, Horizental Cylinders)

$$A_w := \pi \cdot \frac{\left(D_{darmout}\right)}{12}$$

A_w is the area of the wrapped conduit surface for 1 hour fire barrier per linear ft in ft^2/ft

$$A_w = 1.571$$

$$Q_c(t) := h_c(t) \cdot A_w \cdot \left(T_{sw}(t) - T_{ar}\right)$$

Q_c is the heat transferred by convection from the wrappd conduit surfece in Btu/hr-ft

b) Calculation of the Heat Transferred to the Surrounding by Radiation from the Wrapped Conduit Surface

$\sigma := 0.1714 \cdot 10^{-8}$ Stephan-Boltzman constant in Btu/hr-ft^2-R^4

$\varepsilon_w := 0.7$ Emissivity of the wrapped conduit surface (Darmatt)

$$Q_r(t) := \sigma \cdot \varepsilon_w \cdot A_w \cdot \left[\left(T_{sw}(t)\right)^4 - \left(T_{ar}\right)^4\right]$$

Qr is the heat transferred by radiation to the surrounding from the wrapped conduit in Btu/hr-ft

c) Total Heat Transferred by Convection and Radiation from the Wrapped Conduit Surface

$$Q_{cr}(t) := Q_c(t) + Q_r(t)$$

Q_{cr} is the total heat transferred by convection and radiation from the wrapped conduit surface to its surroundings

$t := 550$

Given

$Q_{cond} = Q_{cr}(t)$

$T_{surface} := Find(t)$

$T_{surface} = 566.735$

$T_{surface}$ is the surface temperature of the Darmatt layer, this value is iterated until the heat dissipated by the Darmatt surface is equal to the heat generated by the cable inside the conduit

$h_c\left(T_{surface}\right) = 0.434$ $Q_r\left(T_{surface}\right) = 4.537$ $Q_c\left(T_{surface}\right) = 2.273$

$Q_{cr}\left(T_{surface}\right) = 6.81$

3) **Temperature Drop Through the Darmatt Layer**

$K_{darmattin} = 0.783$ — $K_{darmattin}$ is the Darmatt Conductivity in Btu in/hr-ft^2-^oF

$K_{darmatt} = \frac{K_{darmattin}}{12}$ — $K_{darmatt}$ is the Darmatt Conductivity in Btu/hr-ft^oF

$K_{darmatt} = 0.065$

$D_{darmout} = 6$ — $D_{darmout}$ is the outside diameter of the Darmatt layer in inches

$D_{darmin} = D_{condout}$ — D_{darmin} is the inside diameter of the Darmatt in inches or the outside diameter of the conduit

$R_{darmatt} = \left(\frac{1}{2\cdot\pi}\right)\cdot\left(\frac{1}{K_{darmatt}}\right)\cdot\ln\left(\frac{D_{darmout}}{D_{darmin}}\right)$ — $R_{darmatt}$ is the thermal resistance of the Darmatt layer in ^oR-ft/watts

$R_{darmatt} = 1.315$

$\Delta T_{darmatt} = Q_{cond}\cdot R_{darmatt}$ — $\Delta T_{darmatt}$ is the temperature drop through the Darmatt material in degrees Rankine

$\Delta T_{darmatt} = 8.953$

$\Delta T_{darmattc} = \left(\frac{5}{9}\right)\cdot\Delta T_{darmatt}$ — $\Delta T_{darmattc}$ is the temperature drop through the Darmatt material in ^oC

$\Delta T_{darmattc} = 4.974$

4) **Temperature Drop Through the Conduit Wall**

$D_{conduit} = 3.00$ — $D_{conduit}$ is the nominal diameter of the conduit in inches

$D_{condout} = 3.5$ — $D_{condout}$ is the outside diameter of the conduit in inches

$t_{cond} = 0.205$ — t_{cond} is the conduit wall thickness in inches

$D_{condin} = D_{condout} - 2\cdot t_{cond}$ — D_{condin} is the inside diameter of the conduit in inches

$D_{condin} = 3.09$

$\rho_{cond} = 2.08$ — ρ_{cond} is the thermal resistivity of the conduit material in ^oC-cm/watt

$R_{cond} = 0.00522 \cdot \rho_{cond} \cdot \ln\left(\frac{D_{condout}}{D_{condin}}\right)$

R_{cond} is the thermal resistance of the conduit in °C-ft/watt, 0.00522 is a conversion to ft from cm and combination of constants {(1/2π)(1ft/12in)(0.3937in/cm)}

$R_{cond} = 0.001$

$\Delta T_{conduit} = Q_{condw} \cdot R_{cond}$

$\Delta T_{conduit}$ is the tempreture drop through the conduit in °C

$\Delta T_{conduit} = 0.003$

5) <u>Calculation of the Temperature drop through the Air Space Between the Cable Surface and the Inside Surface of the Conduit</u>

$A' = 3.2$

$B' = 0.19$

A' & B' are constants used to determine the thermal resistance between the cable surface and the inside surface of the conduit

$D_{cable} = 2.42$

D_{cable} is the diameter of the cable in inches

$R_{sc} = \frac{A'}{D_{cable} + B'}$

R_{sc} is the thermal resistance of the air gap between the cable surface and the inside surface of the conduit in °C-ft/watt

$R_{sc} = 1.226$

$\Delta T_{air} = Q_{condw} \cdot R_{sc}$

ΔT_{air} is the temperature drop in the air space between the cable surface and the inside surface of the conduit in °C

$\Delta T_{air} = 2.445$

6) <u>Calculation of the Temperature Drop from the Metal Conductor Surface to the Surface of the Cable</u>

$\rho_i = 500$

ρ_i is the thermal resistivity of the insulation surrounding one of the conductor in °C-cm/watt

$\rho_j = 500$

ρ_j is the thermal resistivity of the individual and overall jacket in °C-cm/watt

$\rho_{3j} = 0.5$

ρ_{3j} is the thermal resistivity of the armor in °C-cm/watt

$d = 0.528$ d is the diameter of the conductor metal of one conductor in inches

$t_i = \frac{8}{64}$ t_i is the insulation thickness in inches

$t_j = \frac{6}{64}$ t_j is the individual jacket thickness in inches

t_{oj} is the overall jacket thickness in inches

$$t_{oj} = \frac{D_{cable} - 2 \cdot 0.025 - 2.15 \cdot \left[d + 2 \cdot \left(t_i + t_j\right)\right]}{2} \qquad t_{oj} = 0.147$$

$t_a = 0.025$ t_a is the armor thickness

$d_j = d + 2 \cdot t_j + 2 \cdot t_i$ d_j is the diameter over the individual conductor jacket in inches

$d_j = 0.966$

$d_i = d + 2 \cdot t_i$ d_i is the diameter over the insulation for one conductor in inches

$d_i = 0.778$

$d_{3j\phi} = 2.15 \cdot d_j + 2 \cdot t_{oj}$ $d_{3j\phi}$ is the diameter over the overall jacket in inches

$d_{3j\phi} = 2.37$

$d_{3ju} = d_{3j\phi} - 2 \cdot t_{oj}$ d_{3ju} is the diameter under the overall jacket in inches

$d_{3ju} = 2.076$

$d_{arm} = d_{3j\phi} + 2 \cdot t_a$ d_{arm} is the cable overall diameter (including the armor) in inches

$d_{arm} = 2.42$

$$R_{ij} = 0.00522 \cdot \left[2 \cdot \left(\rho_i \cdot \ln\left(\frac{d_i}{d}\right) + \rho_j \cdot \ln\left(\frac{d_j}{d_i}\right)\right) + 3 \cdot \rho_j \cdot \ln\left(\frac{d_{3j\phi}}{d_{3ju}}\right) + 3 \cdot \rho_{3j} \cdot \ln\left(\frac{d_{arm}}{d_{3j\phi}}\right)\right]$$

$R_{ij} = 4.188$ R_{ij} is the therma resistance from the metal conductor surface to the surface of the cable in °C-ft/watt. 0.00522 is a conersion to feet from centimenters and the combination of constants {(1/2π)(1ft/12in)(0.3937 in/cm)}

$$\Delta T_{cable} = \frac{Q_{condw}}{3} \cdot R_{ij}$$

ΔT_{ij} is the tempreture drop from the surface of the metal conductor to the surface of the cable in °C

$\Delta T_{cable} = 2.785$

7) **Conductor Temperature**

The conductor temperature inside the conduit is equal to the temperature drop through the Darmatt layer, the conduit, the air space between the cable surface and the inside surface of the conduit, and the temperature drop from the metal conductor surface to the surface of the cable plus the Darmatt layer surface temperature

$$\Delta T_{total} = \Delta T_{darmatte} + \Delta T_{conduit} + \Delta T_{air} + \Delta T_{cable}$$

ΔT_{total} is the total temperature drop from the conductor surface to the surface of the Darmatt

$$\Delta T_{total} = 10.206$$

$$T_{conductor} = \left[T_{surface} \cdot \left(\frac{5}{9} \right) - 273 \right] + \Delta T_{total}$$

$T_{conductor}$ is the conductor tempreture in ^{o}C

$$T_{conductor} = 52.059$$

WOLF CREEK
NUCLEAR OPERATING CORPORATION

Richard A. Muench
Vice President Engineering

May 30, 1996

ET 96-0035

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Mail Station P1-137
Washington, D. C. 20555

Reference: Letter WO 96-0065, dated April 18, 1996, from O.L. Maynard, WCNOC, to USNRC
Subject: Docket No. 50-482: Correction to Information for Revision to Technical Specification3/4.8.1, "Electrical Power Systems - A.C. Sources"

Gentlemen:

This letter transmits a corrected page as requested in telephone conversations between Mr. Jim Stone, Nuclear Regulatory Commission and Mr. Steve Wideman, Wolf Creek Nuclear Operating Corporation. Page 2 of 4 of the Attachment to the Reference, "Insert B," was inadvertently transmitted with information from an earlier revision relating to adherence to ASTM Standards. The Attachment to this letter corrects the information and replaces page 2 of 4 of the Attachment to the Reference.

The conclusions reached in the Safety Evaluation, No Significant Hazards Consideration Determination, and Environmental Impact Determination are not affected by these revised pages.

If you have any questions concerning this matter, please contact me at (316) 364-8831, extension 4034, or Mr. Terry S. Morrill, at extension 8707.

Very truly yours,

Richard A. Muench

Richard A. Muench

RAM/jra

Attachment

cc: C. W. Allen (KDHE), w/a
L. J. Callan (NRC), w/a
W. D. Johnson (NRC), w/a
J. F. Ringwald (NRC), w/a
J. C. Stone (NRC), w/a

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INSERT "B"

DIESEL FUEL OIL TESTING PROGRAM

In accordance with Technical Specification 6.8.4, a Diesel Fuel Oil Testing Program to implement required testing of both new fuel oil and stored fuel oil shall be established. For the intent of this specification, new fuel oil shall represent diesel fuel oil that has not been added to the Diesel Fuel Oil Storage Tanks. Once the fuel oil is added to the Diesel Fuel Oil Storage Tanks, the diesel fuel oil is considered stored fuel oil, and shall meet the Technical Specification requirements for stored fuel oil.

Tests listed below are a means of determining whether new fuel oil is of the appropriate grade and has not been contaminated with substances that would have an immediate detrimental impact on diesel engine combustion. If results from these tests are within acceptable limits, the new fuel oil may be added to the storage tanks without concern for contaminating the entire volume of fuel oil in the storage tanks. These tests are to be conducted prior to adding the new fuel to the storage tanks, but in no case is the time between receipt of the new fuel oil and conducting the tests to exceed 30 days. The tests, limits, and applicable ASTM standards being used to evaluate the condition of new fuel oil are:

1. By sampling new fuel oil in accordance with ASTM D4057 prior to addition to storage tanks and:

2. By verifying in accordance with the tests specified in ASTM D975-81 prior to addition to the storage tanks that the sample has:

    a) An API Gravity of within 0.3 degrees at 60 °F or a specific gravity of within 0.0016 at 60/60 °F, when compared to the supplier's certificate or an absolute specific gravity at 60/60 °F or greater than or equal to 0.83 but less than or equal to 0.89 or an API gravity of greater than or equal to 27 degrees but less than or equal to 39 degrees;

    b) A kinematic viscosity at 40 °C of greater than or equal to 1.9 centistokes, but less than or equal to 4.1 centistokes, if gravity was not determined by comparison with the supplier's certification;

    c) A flash point equal to or greater than 125 °F; and

    d) A water and sediment content of less than or equal to 0.05% when tested in accordance with ASTM D1796-83.

Failure to meet any of the above limits is cause for rejecting the new fuel oil, but does not represent a failure to meet the Limiting Condition for Operation of Technical Specification 3.8.1.1, since the new fuel oil has not been added to the diesel fuel oil storage tanks.

Within 30 days following the initial new fuel oil sample, the fuel oil is analyzed to establish that the other properties specified in Table 1 of ASTM D975-81 are met, when tested in accordance with ASTM D975-81, except that the analysis for sulfur may be performed in accordance with ASTM D1552-79, ASTM D2622-82, or ASTM D4294-90. An exception to ASTM D129, which is specified in ASTM D975-81, has been taken. ASTM D129 uses a Barium precipitation method for the determination of sulfate after oxidation has occurred. The use of any wet lab sulfate analysis is acceptable since the determination is made in the aqueous rinse water for the oxidation process. In the event the correct fuel oil properties are not met, Action g provides an additional 30 days from the time that it is determined that the correct fuel oil properties are not met to meet the Diesel Fuel Oil Testing Program limits. The additional 30 day period is acceptable because the fuel oil properties of interest, even if they are not within limits, would not have an immediate effect on emergency diesel generator operation. The diesel fuel oil surveillance in accordance with the Diesel Fuel Oil Testing Program will ensure the availability of high quality diesel fuel oil for the emergency diesel generators.

At least once every 31 days, a sample of fuel oil is obtained from the storage tanks in accordance with ASTM D2276-83. The particulate contamination is verified to be less than 10 mg/liter when checked ~~based on~~ in accordance with ASTM D2276-83, Method A. The filter size for the determination of particulate contamination will be 3.0 micron instead of 0.8 micron as specified by ASTM D2276-83. The filtered amount of diesel fuel oil will be approximately one liter when possible. Also, it is acceptable to obtain a field sample for subsequent laboratory testing in lieu of field testing.

Fuel oil degradation during long term storage shows up as an increase in particulate, due mostly to oxidation. The presence of particulate does not mean the fuel oil will not burn properly in a diesel engine. The particulate can cause fouling of filters and fuel oil injection equipment which can cause engine failure.

The frequency for performing surveillance on stored fuel oil is based on stored fuel oil degradation trends which indicate that particulate concentration is unlikely to change significantly between surveillances.