Application Note AN 84/01

Pressure Transducer Temperature

Isolation Using Tubing

(Steady State Condition)

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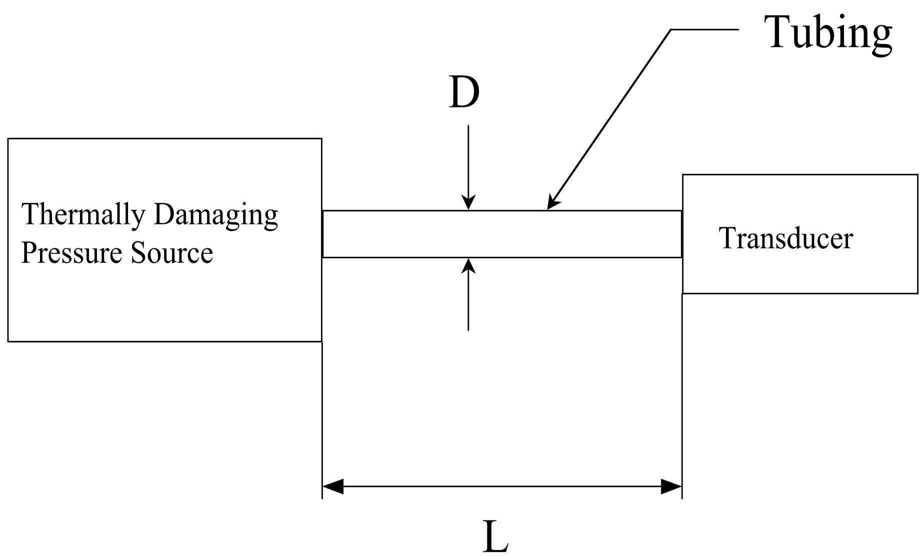
Introduction

In cases where it is desired to make pressure measurements, and the pressure media is at a temperature which exceeds the allowable limits of an available transducer, tubing or pipe may be used to isolate the transducer. It is the purpose of this paper to consider the variables involved, and for the steady state condition, draw curves, which may be used for advising customers who have encountered this problem.



Analysis of the Problem

First, let us consider likely paths for heat to reach the transducer and logically decide the one most eligible for detailed examination.

1. Heat transfers by conduction, convection, and radiation. If the pressure source is contained within an insulated vessel, heat transfer by radiation is sufficiently small and can be neglected. Two paths exist, for heat transfer by convection and conduction:
    a. Through the tube or pipe wall
    b. Through the pressure media.
2. The pressure media is a gas or liquid, and will have a coefficient of thermal conductivity on the order of 0.1 BTU/hr-ft-°F. Any metal will have a coefficient greater than 10 BTU/hr-ft-°F, a difference of two orders of magnitude. From this comparison, the tubing wall will contribute to a much greater extent to determine the transducer temperature.

Derivation of Formula and Curves

The thin walled tube is modeled as a fin operating in conduction and convection, similar to a heat sink fin. The fin is of finite length, and loses heat by convection at its end.

The temperature profile[1] is:

$$\frac{T - T_\infty}{T_o - T_\infty} = \frac{\cosh m(L - x) + (h/mk)\sinh m(L - x)}{\cosh mL + (h/mk)\sinh mL} \qquad (1)$$

Where

$$m^2 = \frac{hP}{KA}$$

And

T = Temperature of at point of interest on fin
T_∞= Temperature of environment, taken as 100F for this analysis
T_o= Temperature of pressure source of interest
L = Length of tubing
X = distance from pressure source
H = Heat transfer rate from tube to still air by natural convection, taken as 1.44 BTU/hr/ft^2/ºF
P = perimeter of fin, here taken as the outside diameter D_1 times π
K = coefficient of heat transfer, taken as16 BTU/hr/ft/ºF
A = area of cross section of fin, here taken as the difference of areas of outside diameter D1 and inside diameter D2, or $\frac{\pi}{4}(D_1^2 - D_2^2)$

This equation simplifies in two ways –

1. We are interested in the temperature at the transducer, at length L. The numerator will reduce to unity.
2. In the denominator, the cosh term is more significant, two orders of magnitude greater than the sinh term. The sinh term will be disregarded for simplicity.

Equation (1) then simplifies to:

$$\frac{T - T_\infty}{T_o - T_\infty} = \frac{1}{\cosh mL} \qquad (2)$$

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[1] Holman, J.P., *Heat Transfer*, McGraw Hill, 1986, p. 43-45

Maintaining consistent units introduces a factor of 12, to convert from feet to inches. The heat transfer coefficients are expressed in terms of feet, while diameters and tube length is expressed in inches. Equation 2, with diameters and coefficients inserted for direct use, is:

$$\frac{T - T_\infty}{T_o - T_\infty} = \frac{1}{\cosh\left(\sqrt{4hD_1/12k(D_1^2-D_2^2)}\; L\right)} \qquad (3)$$

Where

T = Temperature of at point of interest on fin
T_∞= Temperature of environment, taken as 100F for this analysis
T_o= Temperature of pressure source of interest
L = Length of tubing, in inches
H = Heat transfer rate from tube to still air by natural convection, in BTU/hr/ft^2/ºF
K = coefficient of heat transfer, in BTU/hr/ft/ºF
D_1 = outside diameter, in inches
D_2 = inside diameter, in inches

The unit conversion is taken care of by the factor of 12. The factor of 4 is a result of the area computation (D_1^2-D_2^2). The π's from area and perimeter cancel out. The L factor is not under the radical sign.

The coefficient of heat transfer is very conservative, taken at 16 BTU/hr/ft/ºF. For various materials, the coefficient of heat transfer is listed below[2]:

Material	BTU/ft-h-°F
Inconel 625	5.6
Inconel 718	6.5
15-5 PH	10.3
316 SS	9.4
Nickel 200 (99%Ni)	40.4
Monel 400 (63Ni 31Cu)	12.5
Monel 401 (42Ni 53Cu	11
Monel R405 (63Ni 31Cu)	12.5
Monel 450 (31Ni 66Cu)	17
Monel K-500 (63Ni 30Cu)	10.1
Brass (70Cu 30Zn)	70
Copper	226
Commercially Pure Titanium	9.2
Alpha Titanium	4.4

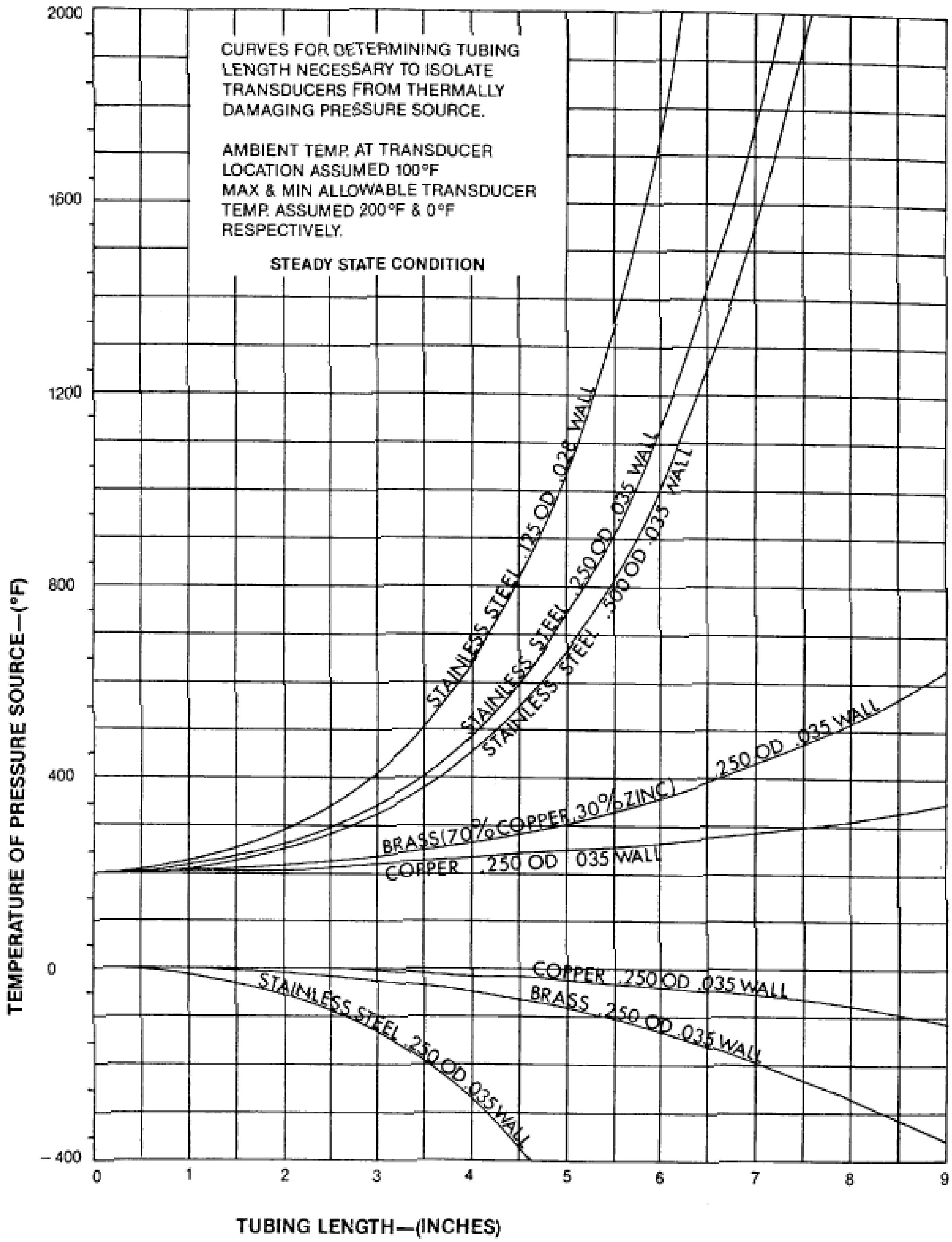
[2] From Metals Handbook, Vol 1 & 2, Properties and Selection, Irons and Steels, and Properties and Selection, Nonferrous Alloys.

Equation 3 is plotted for extreme temperature conditions of the pressure source (t_o) assuming an ambient temperature around the transducer (t_∞) of 100°F and an heat transfer rate (h) from the tube to still air of 1.44 BTU/hr/ft^2/ºF. To account for heat conductivity through the pressure media, and introduce a safety factor, the minimum allowable temperature limits for the transducer are assumed to be 200°F and 0°F, respectively.

Application of the Curves

From the curves, for a given length of tubing, better isolation is obtained with steel, rather than other materials, such as brass or copper. Where frequency response is a consideration, use steel tubing, to minimize the length. At temperatures above 1000°F, brass and copper use is limited. Smaller diameter tubing requires shorter lengths, to isolate the transducer, for a given source temperature. A compromise must be made, between tubing diameter and length, and frequency response.

As a rule of thumb, one foot of steel tubing, any diameter, will isolate a transducer from any temperature.


CURVES FOR DETERMINING TUBING LENGTH NECESSARY TO ISOLATE TRANSDUCERS FROM THERMALLY DAMAGING PRESSURE SOURCE.
AMBIENT TEMP. AT TRANSDUCER LOCATION ASSUMED 100°F
MAX & MIN ALLOWABLE TRANSDUCER TEMP. ASSUMED 200°F & 0°F RESPECTIVELY.
STEADY STATE CONDITION
STAINLESS STEEL .125 OD .028 WALL
STAINLESS STEEL .250 OD .035 WALL
STAINLESS STEEL .500 OD .035 WALL
BRASS (70% COPPER, 30% ZINC) .250 OD .035 WALL
COPPER .250 OD .035 WALL
COPPER .250 OD .035 WALL
BRASS .250 OD .035 WALL
STAINLESS STEEL .250 OD .035 WALL
TEMPERATURE OF PRESSURE SOURCE—(°F)
2000
1600
1200
800
400
0
-400
0
1
2
3
4
5
6
7
8
9
TUBING LENGTH—(INCHES)