FORMULAS FOR MODELING AND PERFORMANCE TESTING R.F. ADMITTANCE PROBES USED FOR LEVEL MEASUREMENT

INTRODUCTION

A selected sensing probe and electronic module combination have a specific inherent gain and sensitivity. These together, must be adequate to perform properly and reliably in a specific level measurement installation.

The equations describing the net result of all these variables in a particular level installation are very complex, typically fourth order. This is true because the location of the probe in the tank, size of tank, probe model, "Dc" of the process material, and the inherent gain of the probe/module combo. All these factors interact in a nonlinear, complex manner.

Delta Controls has simplified the equations and replaced them with a graph and some simple math based on "Sensing Units". This allows the performance of a probe/module combo, installed in a particular service, to be modeled and evaluated before committing to its use. This simplified modeling is easy to use and is adequate for most industrial applications.

The procedure is to first select a probe/module combo which has desirable physical attributes such as size, ground reference, etc. The combo is then modeled; if it does not have enough gain, then select another combo and repeat the modeling procedure until an adequate one is found. Contact Delta Controls if the application is difficult or if it requires a non standard combo or configuration.

TERMS AND DEFINITIONS

"Dc" Stands for "Dielectric Constant" and is a dimensionless number which describes the ease with which an R.F. wave is conducted through a particular process material as compared to its conduction through empty space. Empty space has an assigned value of 1.0. Any atoms added to empty space increase the "Dc" number. Some atom types facilitate conduction better than others. The only way to determine a "Dc" is to measure it using a prescribed apparatus. Fortunately, "Dc" is known for most materials and is cataloged or available from the process material maker.

"SU" Stands for "Sensitivity Unit"; which is a value that has been linearized and made proportional to the electrical change caused by a process material level changing on a sensing probe.

"ISU" Is the increase in "SU" occurring as the process material covers one inch (25mm) of sensing probe.

"QSU" Is the total increase in "SU" units when the process material has covered the active sensing portion of the probe.

"BSU" Equivalent amount of "SU" due to the presence of the probe body, shield, and ground reference.

"RSU" Total net "SU" quantity after the active probe is totally covered by the process material (includes "BSU").

"SSU" Minimum change in "SU" required for an electronics module to change from "off" to "on" or vice versa.

"MSU" Maximum probe coverage switch point setting, in inches of active sensing probe.

"DSU" Maximum "on" to "off" differential switch point action. In inches (25mm) increments.

SELECTING THE SENSING PROBE

REFER TO APPLICATION NOTE NO. AN-10002 FOR DETAILED INFORMATION REGARDING SELECTION OF PROBE TYPES AND THE PREFFERED MOUNTING METHODS.

PERFORMANCE VERIFICATION

PURPOSE: To verify that the selected module/probe combination will operate properly, and to meet the user's expectations in a specific level installation.

4-20 mADC TRANSMITTERS

I. Verify that the combo has enough inherent gain to produce 20.0 mA when the process material covers the probe to a depth which is to be equal to 100% output.

From the probe data sheet:
Minimum Level Change: "QSU" = "ISU" x active length of probe
Minimum Required "QSU" : M/N 172 = 80SU

Verification Test: The probe must produce enough "SU", when covered, to drive the module to 100% output signal.

II. If the probe is more than 120 inches (3000 mm) long or the probe to module separation is more than 100 feet (30 M); then: Verify that the module/probe combo has enough range capacity for the specified level installation.

From the probe data sheet:
Actual Range: "RSU" = "BSU" + "QSU"
Maximum Range:. M/N 172 = 16,000 SU

Verification Test: "RSU" cannot exceed the above listed maximum range of the module to be used.

ON-OFF SWITCHING

Note: (1) Good practice dictates that a switch point should not be set closer than 3" (75mm) to either active end of the sensing probe.
(2) The probe should be long enough to cause "QSU" to be at least 8.0 SU.
(3) Verify that the module range capacity is adequate if the probe to module separation is more than 50 feet (15 M).

I. **Minimum "on to off" differential, in inches:**
From the probe data sheet; read "ISU" . Use the 5 foot curve for an on-off switch inserted in through a flat or curved surface.
For M/N 103 & 105: Minimum "SSU" in inches = $\frac{2.0}{\text{"ISU"}}$
For M/N 107: Minimum "SSU" in inches = $\frac{1.0}{\text{"ISU"}}$
"QSU" = "ISU" x inches probe (8.0 SU minimum)

II. **Maximum switch point setting; In inches of coverage**:
From probe data sheet; add up "BSU"
For M/N 103 & 105: "MSU" = $\frac{4000\text{-"BSU"}}{\text{"ISU"}}$
For M/N 107: "MSU" = $\frac{11{,}000 - \text{"BSU"}}{\text{"ISU"}}$

III. Maximum on to off differential setting band; in inches:
For M/N 105: "DSU" = $\frac{\text{"MSU"}}{\text{"ISU"}}$ For M/N 107: "DSU" = $\frac{\text{"MSU"}}{\text{"ISU"}}$

MODELING EXAMPLE # 1, 4-20 mA TRANSMITTER

PROBLEM: Measure the liquid level in a 5 foot diameter by 11 foot high vertical cylindrical tank. Available process connection is ¾" NPT and is located on the top centerline. Liquid is bromine at 77º F and 5 PSIG. Provide a 4-20 mADC output signal. Locate the electronics module 50 feet away in a safe area.

INITIAL SELECTION: A P51 probe with a M/N 172 electronics module; because this is the simplest and lowest cost probe. Verify that this combo will perform in this application.

FROM P51 DATA SHEET GRAPH: Read "ISU"
Bromine Dc = 3.1, "ISU" = 2.0
Refer to the previous page for definitions and modeling formulas.

A. Verify that the combo has enough inherent gain to produce a full scale 4-20 mA signal.
Actual "SU" Increase: "QSU" = "ISU" x active probe length = 2.0 x 132" = 264 SU
Minimum "QSU" required by the M/N 172 to output 20 mA is 80 SU
∴Conclusion: The P51/172 combo has sufficient inherent gain and sensitivity to work well in this application and easily operates from the 264 SU produced.

B. Because the probe is more than 10 feet long: Verify that the M/N 172 module has enough range capacity to produce only 20.0 mA when the material is completely covering the active probe.

FROM P51 DATA SHEET: Add up and determine "BSU"

Base due to gland/body	= 121
Length of probe (132 inch) x 2.0	= 264
Inactive shield length	= -0-
Temperature extension length	= -0-
Distance to remoted module: (600 inch) x 4.5	= 2700
TOTAL "BSU"	= 3085

Total SU at 100% coverage: "RSU" = "BSU" + "QSU" = 3085 + 264 = 3349 SU.
Maximum range ("RSU") for M/N 172 = 16,000 SU.
∴Conclusion: The "RSU" produced is less than the maximum allowable "RSU"; the M/N 172 module will work in this application.

NOTE: The tank will not have to be filled or emptied. The 172 only needs two different known level elevation points, anywhere in the tank, for complete pushbutton output signal calibration.

MODELING EXAMPLE # 2, 4-20 mA TRANSMITTER

PROBLEM: Same as above, except the tank is now filled with mineral oil and only half of the tank is to be measured, 20.0 mA to occur when there is 66 inches of oil in the tank.
Verify that the P51/172 combo will still perform properly.

A. **FROM P51 DATA SHEET GRAPH:**
Mineral oil Dc = 2.1, "ISU" = 1.1
Actual "SU" Increase: "QSU" = 1.1 x 66" = 73 SU. The minimum "QSU" for a M/N 172 module is 80 SU. The inherent gain and sensitivity of the P51/172 combo is not enough and the output signal will not drive to 20.0 mA when the oil rises to 66" height (100%).
Try substituting the P21 probe which has more inherent gain.

B. **FROM P21 DATA SHEET GRAPH:** Read "ISU"
Mineral Oil Dc = 2.1 "ISU" = 4.1
Actual "SU" increase: "QSU" = 4.1 x 66" = 271 SU. This "QSU" exceeds the minimum of 80 required by the 172 module.
∴Conclusion: The P21/172 combo has enough inherent gain and sensitivity to work in this mineral oil application.

C. Because the probe is more than 10 feet long: Verify that the total "SU" ("RSU"), when the output is 20.0 mA (tank half full), does not exceed the maximum range capability of the 172 module.

FROM P21 DATA SHEET: Determine "BSU"

Base due to gland/body	=	137
Length of probe (132 inch) x 5.5 (still 132", even though only 66" is used)	=	726
Inactive shield length	=	-0-
Temperature extension length	=	-0-
Distance to remoted module: (600 inch) x 4.5	=	2700
TOTAL "BSU"	=	3563

Total "SU" at 100% coverage: "RSU" = "BSU" + "QSU" = 3563 + 271 = 3834 SU which is less than the 16,000 SU maximum rangeability of the 172 module.

∴Conclusion: Both the minimum and maximum capabilities of the P21/172 combo will be adequate for the described example #2 application. It will also be very easy to calibrate.

MODELING EXAMPLE # 3, 4-20 mA EXTERNAL CAGE LEVEL TRANSMITTER

PROBLEM: Measure a 24" change of #2 fuel oil level in a continuous process vessel @ 50 PSIG and 190ºF.

INITIAL SELECTION: P31 external cage probe (this is a continuous process) and a M/N 172 module. NOTE: The determination of "BSU" and "RSU" can be dispensed with because the P31 is less than 10 feet long and the module is integrally mounted. The maximum "RSU" range limitation of the 172 module will not be exceeded.

FROM THE P31 DATA SHEET GRAPH: Read "ISU", get Dc value of #2 fuel oil from a reference book
Dc = 2.7 units, "ISU" = 4.0
"QSU" = 4.0 x 24 inches change = 96 SU produced
∴Conclusion: The P31/172 combo will be adequate because the minimum required "QSU" of the M/N 172 is 80 SU, which is less than the 96 SU produced.

MODELING EXAMPLE # 4, ON/OFF SWITCHING SERVICE

PROBLEM: Produce a high level alarm 4 inches below the top of a 4 foot high x 15 foot long horizontal cylindrical tank. A 2" NPT opening is available on the top centerline of the tank. A 3"/150# R.F. flanged opening is located on the horizontal centerline of the tank. The electronics are to be mounted 60 feet from the tank, in a safe area. The tank contains unleaded gasoline at 220ºF (105ºC) and 100 PSIG (7 BAR).

INITIAL SELECTION: The top connection must be used because the sensing probe must cross the desired liquid switching elevation. Try a P51 probe with a M/N 105 module with I.S. probe, which is the simplest usable combo.

A. From P51 data sheet graph: Read "ISU" Dc = 1.8 at 220ºF (use the "5 foot" curve to simulate gain from a probe through a curved surface); therefore: "ISU" = 0.65
B. From general installation rules: "Do not place a switch point closer than 3 inches to either active sensing probe end", see first page of this document. When set 4.0 inches down, the switch point differential must not be more than 1.0 inches (4" - 3" = 1") to comply with this rule. From the 105 datasheet; "SSU" = 2.0 SU. Minimum switching differential = 2.0 ÷ "ISU" = 2.0 ÷ 0.65 = 3.1 inches differential which exceeds the specified allowable ±1" differential.
∴Conclusion: The P51/105 combo does not have enough inherent gain and sensitivity to perform as required.
C. Select a probe having more inherent gain, such as the P21. From the P21 data sheet graph: "ISU" = 3.4 Minimum switching differential ("SSU") = 2.0 ÷ 3.4 = 0.59 inches. This is within the ≠ 1 inch maximum allowable differential and the combo has adequate sensitivity for the application. Produced "QSU" = "ISU" x active inches = 3.4 x (4.0 + 3.1) inches = 24 SU.
D. Because the probe to module separation is more then 50 feet: Verify that the total "RSU" at the switch point, does not exceed the maximum range ("RSU") of the 105 module.

FROM THE P21 DATA SHEET: Determine "BSU"

Base Gland/Body:	= 137 SU
Probe Length: 5.5 x 12"	= 66
Shield + Extension Length: 31 x 3"	= 93
Remoted Electronics: 4.5 x 720"	=3240
"BSU"	=3536 SU

"RSU" = "BSU" + "QSU" = 3536 + 24 = 3560 "SU" which is less than the 4000 SU maximum of the M/N 105 range (found in the 105 datasheet).

∴Conclusion: Inherent gain, sensitivity, and rangeability of the P21/105 combo is adequate for this application.

MODELING EXAMPLE # 5 ON/OFF SWITCHING SERVICE

PROBLEM: The tank in Example #4 is filled with gasoline. Produce a warning alarm when the gasoline level falls to less than 50% full. The module is to be integrally mounted on the probe head; the area is Class 1, Division 1, Group D hazardous.

INITIAL SELECTION: The 3"/150#RF side connection is located at the desired switching elevation and a horizontal sensing probe mounted on that connection can be used. From the Application Note AN-10002: An inactive extension is required because of the flanged nozzle cavity. The required length is 1" more than the nozzle length. From the vessel drawings, the nozzle length is found to be 4", making the inactive length 5" long. The process temperature is 220°F (105°C) which requires a 3" (75 mm) temperature extension for an integrally mounted electronics module. The area is explosion hazardous, requiring a M/N 105 with intrinsically safe probe circuit.

A. From P51 data sheet; the "ISU" is 0.75. The 105 "SSU" = 2.0, 2.0÷0.75 = 2.7" of active probe coverage is required. Add ±2.7" required, plus two 3" end-of-probe increments, for a total of 12" of active length required. Add the 5" inactive section for a total insertion of 17". The entire active probe length is uncovered by a 0.25" (6mm) decrease in level below the tank centerline and switching occurs. The produced "QSU" = "ISU" x active inches = 0.75 x 12 inches = 9 QSU. This is within the 8.0 minimum "QSU" requirements for good practice.

B. The probe does not exceed 10 feet in length and the probe to module separation is less than 50 feet. It is not necessary to determine "RSU" (range limitation) for the P51/105 combo.

∴Conclusion: The P51/105 combination has enough inherent gain, sensitivity, and rangeability to reliably switch in this application.

NOTES FOR SELECTING 4-20 mA TRANSMITTERS FOR INTERFACE

1. "Zero" output signal is usually set when the tank is full of the material with the lowest dielectric constant (usually the upper fluid, which is typically a hydrocarbon).
2. "100%" output signal is usually set when the tank is full of the material with the highest dielectric constant (usually the lower fluid, which is typically mostly water).
3. "RSU" is calculated based on the tank being full of the higher dielectric material.
4. A poorly defined interface line is fairly common in separating facilities. This condition is also known as "being cloudy" or having a "rag layer". Calibration is performed in the normal manner, the M/N 172 module will average out the dielectric constant difference between the two liquids. The output signal will usually indicate that the interface position is approximately at one half of the "rag layer" thickness.
5. A solids bed covered by water cannot be detected or measured with an R. F. probe. The conductive "background" liquid masks the lower dielectric of the solids material and it all appears to be water. Examples: sand in filters, precipitated salt under brine water, and activated carbon in color removal beds. The Model 820 sounding transmitter with interface sensor will usually handle these applications easily and reliably.

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