

ACCURACY JUNGLE TRUE OR FALSE?

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Abstract

Today's advanced vehicles demand high performance data acquisition systems to provide the technologist with test results that can be properly modeled and analyzed. This data must be precise and consistent. There are many systems available in today's marketplace, however selecting the right system may present a challenge. Data acquisition manufacturers often minimize system problems by highlighting performance at unrealistic operation modes. Test engineers may fall into this trap when ignoring the fine print in the manufacturer's data sheet. This "specsmanship" by the manufacturer, if not caught by the instrumentation engineer, can lead to major problems during the flight test program. Knowing in advance how to calculate your system requirements to achieve the proper test results will assure a more successful flight test program. This paper will describe how to correctly assess and evaluate your requirements against true system performance.

Keywords

Data Acquisition, Telemetry, Instrumentation, Measurement Accuracy

Introduction

The object in every flight test program is to validate the aircraft configuration to ensure that it meets its design goals for performance and, more importantly, safety. Measurements must be specified and made to sufficient accuracy to achieve the stated goal.

Each measurement must be analyzed to determine the appropriate sensor type, required accuracy and environment under which it must operate. This analysis extends from the sensor and sensor installation, the wiring and connection to an appropriate signal conditioning circuit, through the transmitting, receiving and recovery of the original data.

Background

There are two main methods of obtaining, transmitting, receiving and recovering data collected during a flight test program. These are Frequency Division Multiplexing (FDM) and Time Division Multiplexing (TDM).

In Frequency Division Multiplexing, each measurement is assigned a defined frequency band or channel. Each input signal is conditioned and fed to a Voltage Controlled Oscillator (VCO). The output frequency of the VCO is equivalent to the input voltage of that channel. The frequencies from each of the measurements are mixed to form a composite output that is transmitted to the ground, fed through a band-pass filter where the frequencies of the individual channels are recovered, and processed by a frequency to voltage converter to recover the original signal.

The FDM method is a continuous time system. Therefore, analog input filtering is critical only to the extent that it is required to prevent adjacent channel interference. The disadvantage of this method is that, in addition to the error of the voltage to frequency conversion in the encoder, there is an error in the frequency to voltage conversion of the decoder. In data reduction, the performance of the band-pass filter is critical to the extent that group delay must be controlled to prevent gross errors. There are always small errors due to this factor. Also, the recovered data is in analog form and is analyzed using a strip chart that has its own errors and limitations on bandwidth and resolution.

In Time Division Multiplexing, each measurement channel is assigned a defined time slot. Each channel is conditioned, sampled and digitized during its allotted time. The digital data from all channels is serialized and frame synchronization information is added to allow recovery of the digitized information. This serial data stream is filtered and transmitted to the ground where it is received and decommutated to recover the original signal.

The TDM system is a sampled data system so aliasing is a concern. The analog input filtering and sample rate of a channel must be selected to ensure aliasing is reduced to an acceptable level. There is also overhead associated with the frame synchronization that increases the required bandwidth of the transmission. The advantage of this method is that, once digitized, no error is introduced in the recovery of the data. Also, since the data is in digital form, it can be more easily analyzed with the assistance of computers.

This paper will focus on Time Division Multiplexing having a Pulse Code Modulated (PCM) output as defined in IRIG-106 Chapter 4. Error sources will be considered up to and including the digitization of the data.

Accuracy Considerations – Sensors

There are many sensor types tailored to make specific measurements such as acceleration, pressure, strain and temperature. Within each sensor type, there are various selections to further tailor the sensor to the required measurement. These include full-

scale range of the sensor, accuracy, excitation requirements and sensitivity, frequency response, and operating environmental conditions.

A word of caution when evaluating any component whose accuracy is stated as a percent of full-scale. Consider the case of a pressure sensor that has a full-scale range of ± 5 psi and an accuracy of ± 1 percent of full-scale range. The full-scale range of the sensor is 10 psi. One percent of this range is ± 0.1 psi. If the required measurement range is 0 to 5 psi, the full-scale range being used is 5 psi. However, the accuracy of the sensor is still ± 0.1 psi (± 1 percent of 10 psi full-scale). This represents an error of ± 2 percent of the 0 to 5 psi range. The sensor should always be selected to provide as close to the required measurement range (plus any necessary overhead) as possible. The effect of the percent of full-scale range specification should be well understood and carefully considered when selecting components and performing an uncertainty analysis.

Beyond the selection of a sensor, there are other factors that can affect the quality and accuracy of the measurement. These include attachment of the sensor to the physical structure being measured. For example, when installing an accelerometer, the mass of the accelerometer must be considered. If it is a significant fraction of the mass of the structure, this will effect the measurement and provide erroneous information. Also, if the measurement axis of the accelerometer is not properly aligned on the structure, the resulting data will be incorrect. This installation and alignment issue applies to all sensors and they all have their own special requirements that must be considered. For strain gauges, the bonding of the gauge to the surface is critical to ensure that the transfer of the strain from the structure to the gauge is optimum. The alignment is also critical to ensure the strain is measured in the required axis. Further, errors due to expansion and contraction of the structure to be measured and any self-heating effects due to the excitation source must be considered. This would be similar in the case of RTDs. The method of bonding the RTD to the structure must guarantee the proper heat transfer. Self-heating effects of the required excitation must also be considered.

The last, but certainly not least, issue that must be considered is the wiring of the sensor to the data system. Improper or careless wiring can be disastrous, causing large errors and noise to be introduced into the measurement. This is especially problematic with low-level signals in the milli-volt range.

The accuracy of the sensors and the effects of installation are critical in the uncertainty analysis of any system. However, the primary focus of this paper is the evaluation and selection of the data acquisition system and the effect of “specsmanship” on this process.

Accuracy Considerations – Data System

Once the sensors have been selected, the accuracy of the data system must be considered. There are several error sources that must be evaluated such as crosstalk and common mode rejection ratio, but in today’s data systems the largest contributors to the overall accuracy of the system are the gain and offset error. These are the subjects of this discussion.

Additionally, since this is a sampled data system, there are errors due to aliasing. In a system where analog anti-aliasing filters are used, the error due to aliasing can be minimized by over-sampling of the channel in the PCM format. Aliasing as it applies to digital filtering will be discussed separately.

Three main stages make up the signal conditioning circuit. These are the gain stage, the filter stage, and the Analog to Digital converter stage. If the signal conditioner employs digital filtering, additional errors due to rounding and aliasing may need to be considered.

Further, the gain has a DC component and an AC component. The advertised specifications normally refer only to the DC accuracy of the card or the system. The user must be cautious and find out whether the advertised specification refers to the card only or if it applies to the total error through the system.

TTC has tried to make the process of determining system accuracy as simple as possible. We specify our DC gain and offset accuracy as ± 0.5 percent of full-scale range over the operating temperature range of -35 to $+85$ degrees C (standard – some cards may be specified at different accuracies). The only parameter specified separately is excitation error. This is necessary as the excitation may or may not be used in a given application.

You will notice the use of the expression “percent of full-scale range”. Yes, TTC makes use of this method of specifying accuracy. Therefore, the user must consider the effect of using less than the full-scale range of the system. If half of the full-scale range is utilized, the accuracy would be ± 1 percent. TTC provides programmable gain in the range of 1 to 1,000 in over 12,000 steps and programmable offset in the range of ± 50 percent of full-scale range in our latest line of signal conditioners to provide sufficient flexibility to ensure as much of the full-scale range of the system as possible can be utilized. This provides maximum accuracy and resolution.

The AC accuracy of the system is specified in dB at a card level. For instance, TTC’s line of digitally filtered cards specifies the data frequency of the channel as the point where it drops to 0.1 dB of the ideal value for the FIR filter. In the case of the 120 tap filter this occurs at 0.86 times the -3 dB frequency. TTC also offers 90, 60 and 40 tap FIR filters and 6 and 8 pole Butterworth, 6 pole Chebyshev and 6 pole Bessel IIR filters. The analog anti-aliasing filter is selected to guarantee minimal error in the pass-band and the ADC samples are phase locked to the format sample rate to guarantee time correlation. The sample rate is multiplied up to a rate that is typically 7 to 14 times the anti-aliasing filter’s -3 dB frequency (this filter is typically a 5 pole Butterworth filter), minimizing aliasing errors.

Aliasing errors can be somewhat difficult to quantify. Often, the physics of the measurement and the sensor will provide some measure of anti-aliasing filtering, but there could also be noise injected into the measurement from an unexpected source that could effect the measurement. The best defense against aliasing errors is to make sure you understand aliasing and the potential effects on the quality of your measurements.

“Specsmanship”

“Specsmanship” is the art of defining the specifications of a product in such a way so as to make it as attractive as possible to the prospective customer. While everyone performs this “specsmanship” to a greater or lesser extent, it becomes problematic when the specifications are obscured or made so difficult to determine so as to easily mislead the potential user.

Consider the case of a strain gauge conditioner that provides constant voltage excitation. TTC’s specification for the DC accuracy of the signal conditioning channel is ± 0.5 percent of full-scale output over the operating temperature range of -35 to $+85$ degrees C and covers all effects of gain and offset. The excitation is specified to be ± 0.3 percent including all effects of line and load regulation over the operating temperature range. This specification is very clear and straight-forward.

An example from another data system manufacturer may be similar to the following.

Nominal channel accuracy of 0.5 percent.

This looks interesting and gets your attention, but the first question that comes to mind is “under what conditions does this apply and is this 0.5 percent total error or ± 0.5 percent?”. Further investigation of the data sheet reveals the following specifications.

Gain accuracy ± 0.5 percent of selected value.

Gain temperature stability of ± 0.5 percent of selected value, including effects of excitation drift.

Excitation accuracy of 0.5 percent.

Load regulation ± 0.5 percent from no load to full load.

Channel offset stability ± 0.5 percent of full-scale over temperature at a gain of 32.

What is the total accuracy of the measurement? Even the gain specification is difficult to quantify as the temperature stability includes the effects of excitation drift. If the two errors are simply summed this yields an error of ± 1 percent over the operating temperature range. Using the sum of the squares method yields an error of ± 0.71 percent. What is the error if you want to use the channel without excitation?

The total accuracy of the channel set to a gain of 32 including errors from all sources would be ± 2.5 percent of full-scale if the errors are summed, or ± 1.12 percent of full-scale using the sum of the squares method.

Which error would you actually see? Offset error generally increases at higher gain. What error would you expect at a gain of 256 or 512, which are common for strain gauge measurements? There is not enough information included to make a determination of total error at gains higher than 32.

Is this what was envisioned when viewing the statement “Nominal channel accuracy of 0.5 percent”?

Consider another example for a system that may be specified as follows.

Gain error of +/- 0.125 percent of full-scale range (total error after gain and offset adjust) for primary gains of 1, 10 and 100 and secondary gain of 1.
Excitation error +/- 0.2 percent of full-scale range.

Wow, this looks fantastic! I want to use this system!

Anytime a specification is given with so many conditions alarm bells should start to ring.

Taking a second look at this specification, many questions come to mind. The first thing I notice is that there is no mention of temperature. Do these specifications apply over the operating temperature range?

What does “total error after gain and offset adjust” mean? How is this accomplished?
What is the total error without adjustment?

The statement that this specification applies with a secondary gain of 1 implies that there are secondary gains other than 1. What are the available gains? What are the gain steps?
How is the accuracy affected at secondary gains other than 1?

There is too much information missing from this specification to make an intelligent decision on the suitability of this system.

Further, since there are differences in the way the specifications are written in the three examples, it becomes difficult to make a fair comparison between them.

Conclusion

Specifying a flight test instrumentation system from the sensors through the wiring and the data acquisition system to the transmitter and recorders is a daunting task. There are pitfalls at every turn and “specsmanship” on the part of the component manufacturers doesn’t make this task any easier.

Just as in the purchases made during every day life, “let the buyer beware” applies to flight test instrumentation. Whether it be in the purchase of a strain gauge or a data acquisition system, the user should educate themselves on the use and possible error sources of the components. The specifications should be studied to make sure that the component will meet the requirements under the conditions to which it will be subjected (temperature, altitude, vibration, etc.).

If there are any doubts, ask questions. Make sure these questions are answered satisfactorily. If there are still unanswered questions or doubts, ask the manufacturer to arrange for a demonstration or, better yet, a unit that you can borrow for a week or two to set up in a real-world situation to see how it performs. Take it over temperature to satisfy yourself that it will meet your requirements. Any reputable manufacturer that stands behind their equipment should be happy for the opportunity to show you how well their equipment performs in a real-world application. After all, that is where the equipment will be used; in the real-world of flight test, one of the most demanding environments in the world.

Remember, if you are responsible to specify a data acquisition system, the success of the flight test program is dependent on your selection. Educate yourself, ask questions, make the right decision!