From: Paul Rebstock — RES
To: Ho Nieh
Date: 02/12/2007 11:57:57 AM
Subject: Fwd: CrossFlowUFM: PJR comments on 2006Oct12 draft SE, and additional thoughts

Ho,

Here is the technical discussion that I mentioned this morning. I don't know to what extent any of this was taken into consideration in the original evaluation of the XFlow UFM or in the subsequent review and retraction. As I hope you can see from the comments, there seems no way to separate the "instrumentation" and "fluid dynamics" aspects of the behavior of this instrument.

- Paul

>>> Paul Rebstock 10/16/2006 11:00 AM >>>

Warren,

Allen has already returned the concurrence package to John. He has concurred with comments. My comments have been incorporated into the mark-up, but I am providing them separately here to help clarify the reasoning behind the indicated changes.

Two other points for consideration in the review if the TR is revised and resubmitted are described below.

- Paul

Additional concerns:

XFlow samples the detailed fluid flow conditions (in particular, the eddie pattern) within a narrow conical volume centered on a straight line through the pipe diameter. The 3-dimensional flow conditions within the truncated cone (the narrow end of the sample volume is inside the vertex) are "captured" in the frequency and phase modulation of narrow-band acoustic pulse. The theory is that a subsequent sounding of the fluid a short distance downstream will find the identical 3-dimensional flow conditions at some later time, and the elapsed time will then yield the fluid axial velocity. I have two concerns with this process:

1. flow profile distortion effects

It is well-known that the fluid velocity is not constant across the diameter of the pipe. The theoretical turbulent flow profile goes from zero velocity at the pipe wall to some maximum value at the pipe axis, following approximately a 4th-order symmetrical polynomial. The average velocity under these conditions is slightly less than 93% of the maximum velocity. If the profile is distorted, then the average will be some other fraction of the maximum. This 7% difference between maximum and average velocities is much greater than the total quoted uncertainty of 0.5% in the overall flow measurement, so the details of the shape of the flow

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velocity distribution across the flow area are important to the successful operation of the instrument. And the difference between the average velocity and the minimum is much greater than this 7%.

For the purposes of illustration, the following discussion will focus on the average and maximum velocities. Consideration of the velocities lower than the average will exacerbate the concerns and will not mitigate any of them. This discussion will also treat the sample zones as simple lines of zero cross-section, ignoring any effects that might result from the actual conical shape. It will also ignore the transit time for the acoustic beam to travel across the diameter of the pipe.

The upstream sample will include all points across the diameter of the pipe at the instant of the sample. These points will be traveling at different speeds, in accordance with the fluid velocity profile. If we assume an average velocity of 20 ft/sec, then the maximum velocity would be about 21.5 ft/sec. A point traveling at the average velocity would require 50ms to traverse the 1ft separation between the upstream and downstream sensors. A point traveling at the maximum velocity would require about 46ms, and slower points would require more time. The difference in flight time for the average and maximum velocities is about 4ms, or about 8% of the average. When a point traveling at the average velocity arrives at the downstream sensing zone, a point traveling at the maximum velocity will have moved almost an inch beyond it. Slower points will obviously arrive later.

This spreading of arrival times means that the fluid conditions sampled at the downstream location are necessarily different from those sampled at the upstream location. Therefore *the acoustic pulse modulation at the downstream location can <u>never</u> match the "corresponding" modulation at the upstream location.*

The effects of the distortion of the downstream flow condition depend upon the details of the flow profile and of the conditions themselves, and therefore cannot be predicted. The algorithm that matches downstream conditions with upstream conditions (so that time-of-flight can be determined) must therefore accommodate this distortion and demand only an approximate matching. But since matching is only approximate, rejection is also only approximate. Thus conditions resembling a sensed upstream condition but not resulting from it may nevertheless be associated with it, and thereby yield an incorrect time-of-flight estimate.

This misidentification error would be exacerbated by swirl, whereby extraneous conditions could be rotated into the downstream detection zone after having avoided detection in the upstream zone. Of course, this effect would depend upon the angular velocity of the swirl, and I have no estimates of reasonable values of that. Therefore this swirl-related detail is just a theoretical possibility from my point-of-view.

All of the foregoing is based upon an assumption of ideal flow conditions (fully-developed flow). Distortion of the flow profile as would be expected in an actual application would not be likely to flatten the profile but rather to increase the difference between the average and localized flow velocities, and so to increase the effects described above.

The upshot of all this is the following question:
Are the cross-diameter patterns of eddies sufficiently unique and stable that the matching of upstream and downstream acoustic signatures will be sufficiently reliable considering random similarities in the eddie patters themselves and considering allowances that must be

accommodated in the pattern identification to account for the distortion caused by nonuniform flow?

2. time-measurement resolution

With a fluid velocity of 20 ft/sec and a sensor separation of 1 ft, the fluid travel time would be 50ms. At 8000 sample per second, the sample period (0.125ms) would be 0.25% of the time-of-flight of the sampled fluid condition. I believe that 20fps is a common upper design limit for FW piping systems, and 8000/sec is my recollection of the XFlow sample rate - that may be inaccurate. If these numbers are correct, the timing resolution error alone would be a significant fraction of the instrument error budget, even if the timing measurement errors were ignored.

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