AN IMPROVED ALGORITHM FOR SPINNER PROFILE ANALYSIS

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SUMMARY

A new approach to the analysis of spinner data is proposed, where the complete set of data (depth, tool velocity, frequency) is regarded as a single set of observations to be fitted to a model of fluid structure (depth, fluid velocity) and a model of tool performance. This approach of treating the entire data set on the same basis is considered to be better than previous methods and more consistent mathematical practice. Multiple observations at calibration stations count in proportion to their number, but repeat observations at other depths contribute equally to the tool model or calibration. If measurements only at a fixed station are considered, the approach is identical to standard calibration cross-plotting.

This analysis method generates fiom a set of measurements at different tool velocities, a single best estimate of fluid velocity against depth. This can be subjectively interpreted. Such interpretations are free of tool bias. If multiple flow rates have been used, a velocity profile is generated for each flow rate. Comparison between these velocity profiles can be used to generate a model of well diameter and feed zone structure.

1. INTRODUCTION

Figure 1 below shows a set of spinner runs during injection into an injection well at Ohaaki.

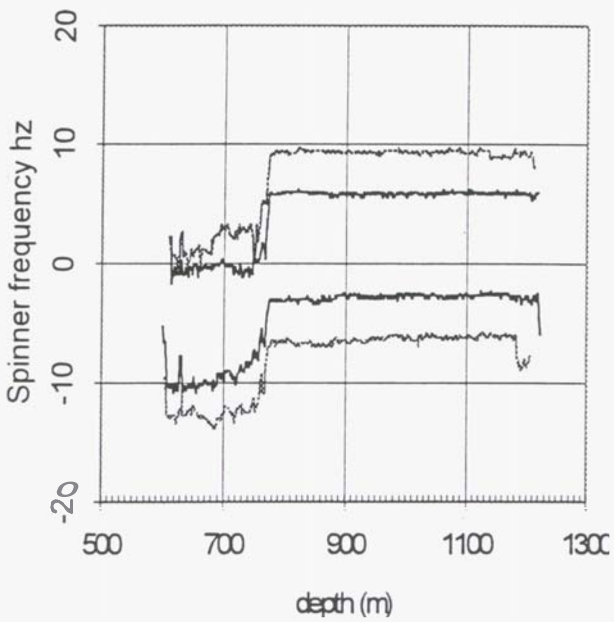

Figure 1. Spinner profiles in Ohaaki injection well.

These profiles require little effort to interpret. The well, which is vertical, has a single loss zone at 790m. Beneath it there is static water in the wellbore. The small feature at the bottom of the well is not significant.

Spinner data is usually more complicated, with varying wellbore diameter and multiple feed zones.
Interpretation of spinner measurements has usually taken one of two routes:

- extensive stations in the casing to calibrate the spinner, followed by use of this calibration to compute fluid velocity from measured frequency
- plotting of frequency against depth and the visual identification of rapid or step changes in spin as loss zones

Both techniques contain some element of subjectivity or bias, in that data from different stations is weighted unequally. It is more desirable to analyse in a manner that treats all data of equal weight, and which relies less on subjective interpretation.

2. SPINNER DATA

2.1 The data set

The measurements from a spinner run are a set of observations, containing as a minimum

- wellheadflowrate W,

plus at each depth:

- depth d_i
- time t_i
- spin frequency A

In addition, there may be recorded:

- tool velocity V_i
- pressure Pi
- temperature T_i

If tool velocity is not recorded it can be computed from depth and time, but this may add significant noise to the record. From the spinner data are extracted

- fluid velocity U_i

and possibly

- wellbore diameter d_i

Despite technological advances, spinner data is characterised by a high level of noise. This limits the ability to extract significant information.

2.2 Tool performance

The frequency recorded by the spinner depends on the velocity of fluid relative to the tool, and possibly also on ambient conditions, particularly temperature. The performance of the spinner may vary with temperature, such as changing bearing friction.

$$f_i = f(V_i - U_i, T_i, ...) \quad (1)$$

Ideally, the relationship is linear:

$$Cf_i = V_i - U_i \quad (2)$$

where C is the calibration constant of the spinner.

In deviated wells the tool will lie against the bottom side of the well, and measure an unrepresentative flow, unless it is centralised.

2.3 Crossplotting

Calibration or crossplotting uses extensive measurements at different logging velocities to establish the relationship between velocity and frequency. The measurements will all be done at the same depth, or over a region of known constant diameter and velocity, such as the casing, to ensure that variations in fluid velocity do not affect the results.

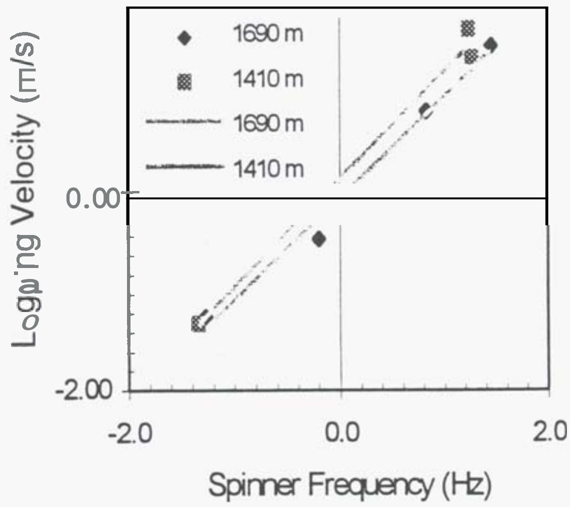

Figure 2. Crossplot of spinner data in Ohaaki well while injecting 37m^3/h.

The crossplot on figure 2 at 1690m shows that a spinner frequency of zero would be measured at zero logging velocity, ie the wellbore fluid is static. At 1410m by contrast zero frequency corresponds to a positive (downwards) velocity, ie fluid is moving down the well. The conclusion is that water is being lost between 1410m and 1690m.

One analysis method is to take such crossplots as the basis for calibration of the tool, and then use the calibration to compute fluid velocity in the rest of the well.

2.4 Profiles

As an alternative to crossplotting, one can simply inspect the spinner profile.

The results illustrated in Figure 3 below are fairly typical in the amount of noise and the presence of some complications. In this case, the spinner bearings were giving problems. The noise is typical. Spinner data frequently requires smoothing or averaging to reduce the noise. Nevertheless, with care one can infer results from such measurements. See for example Goranson and Combs, (1995).

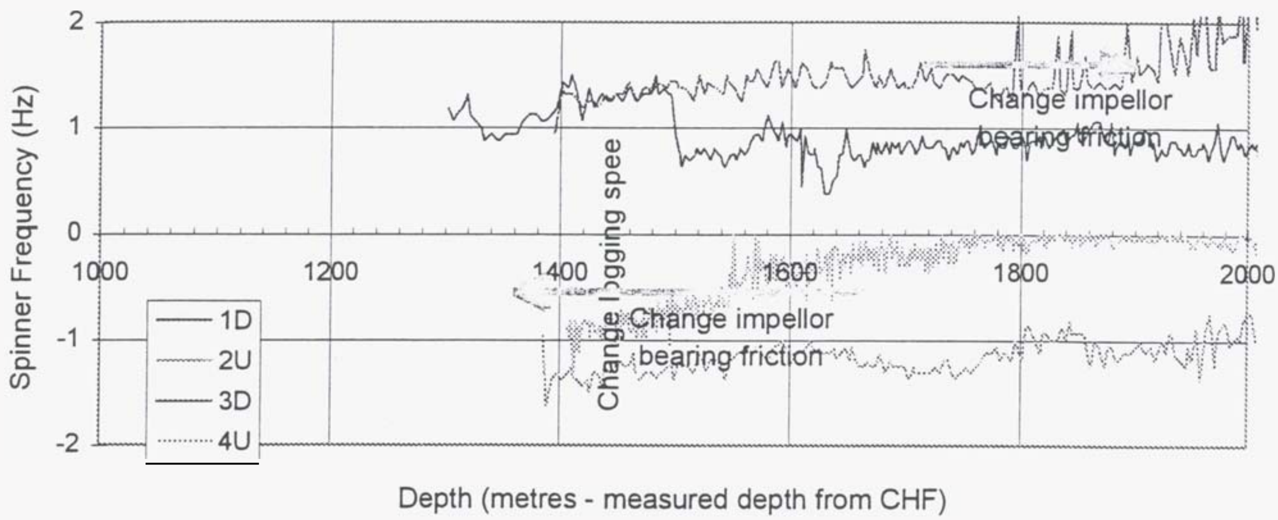

Figure 3. Spinner measurements in Ohaaki well

3. A NEW APPROACH

We take instead the approach that the problem is this: given a set of data, find the optimal model for tool and well. The tool is modelled by a calibration of some form, and the well is modelled by a fluid velocity profile.

3.1 Linear tool model

Let us assume a linear calibration. Then we have at each depth:

$$U_i = V_i - Cf_i \qquad (3)$$

We cannot use this simply as an estimate of fluid velocity as there are one more unknowns (C, U_i) than there are observations. It is also the case that spinner calibrations are frequently not linear. The greatest deviation is that fluid incident from above has a different effect from fluid incident from below. In this case we need a bilinear calibration:

$$U_i = V_i - C f_i \quad f_i > 0 \qquad (4)$$
$$U_i = V_i - D f_i \quad f_i < 0 \qquad (5)$$

3.2 Model regression

We group the data into stations containing one, a few or many data. This achieves some smoothing effect, and reduces the number of fluid velocity values to estimate. It has a further benefit in that data tends to "slide" in the logging direction, particularly at high logging velocities. The grouping smooths this error also, removing the need for estimating a depth correction.

Let the subscript j refer to stations, and to measurements within each station. We now wish to estimate constant calibration constant C, and fluid velocity U_j , to find the best fit to:

$$Cf_{ij} + U_j - V_{ij} = \varepsilon_{ij} \qquad (6)$$

where ε_{ij} is the error which we wish to minimise. This is a straightforward regression, from which we can obtain estimates of fluid velocity and the error in these estimates. A set of Excel Visual Basic modules were used to provide data input and filtering, and to perform the regressions.

A regression performed at a single station is identical to a conventional crossplot. A conventional calibration carried out within the casing is equivalent to grouping all the data within the casing into a single station.

3.3 Example

Figure 4 below shows the interpreted velocity profile in the Ohaaki production well. The data has been grouped into 10m stations, and is plotted with standard errors using a linear tool model. Using a bilinear model made little difference to these examples, although the bilinear fits did show different positive and negative calibration constants.

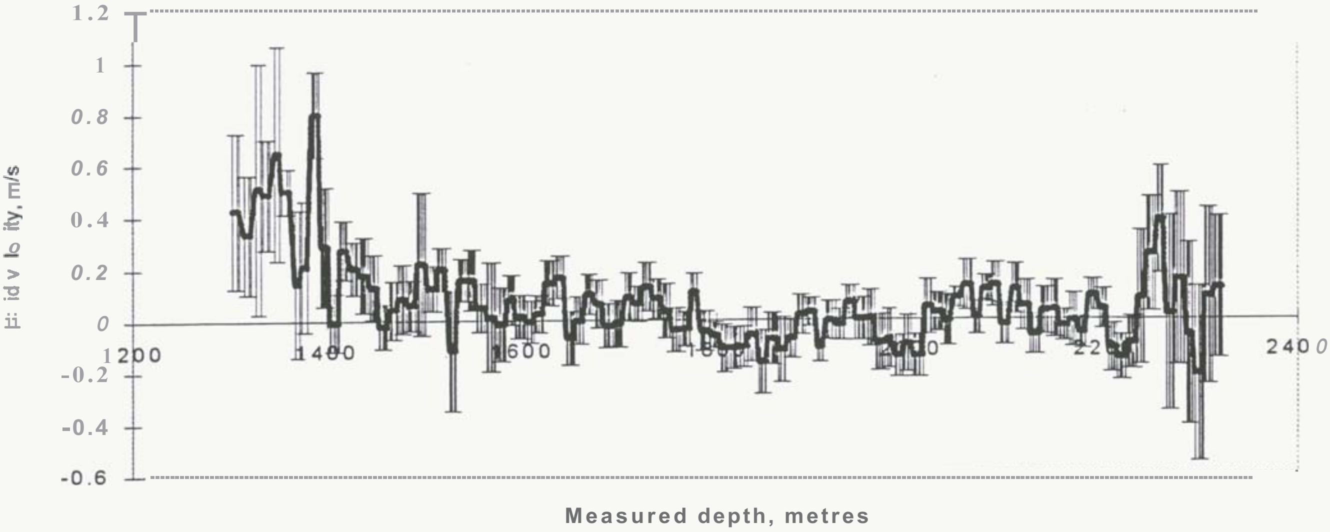

Figure 4. Fluid velocity profile in Ohaaki production well, while injecting $43m^3/h$. Expected relative velocity about 0.3 m/s.

This plot shows a clear interpretation. Fluid velocity declines from positive values to zero around 1400m, and does not differ significantly from zero below 1500m. The fluid loss zone is identified as 1400-1500m. The errors are substantial, indicating that there is no point in attempting a finer interpretation.

The error estimates are valuable, in giving a guide to what can be obtained from the data.

4. APPLICATIONS

4.1 Practical problems.

In practice spinner measurements are subject to many problems. Some data has been omitted from the analysis in figure 4. Figure 5 shows what happens when it is added: The additional data has been added over the interval 1750-2000m. This data is clearly inconsistent with all the other measurements. The spinner was known to be giving problems, so it is concluded that the results are false

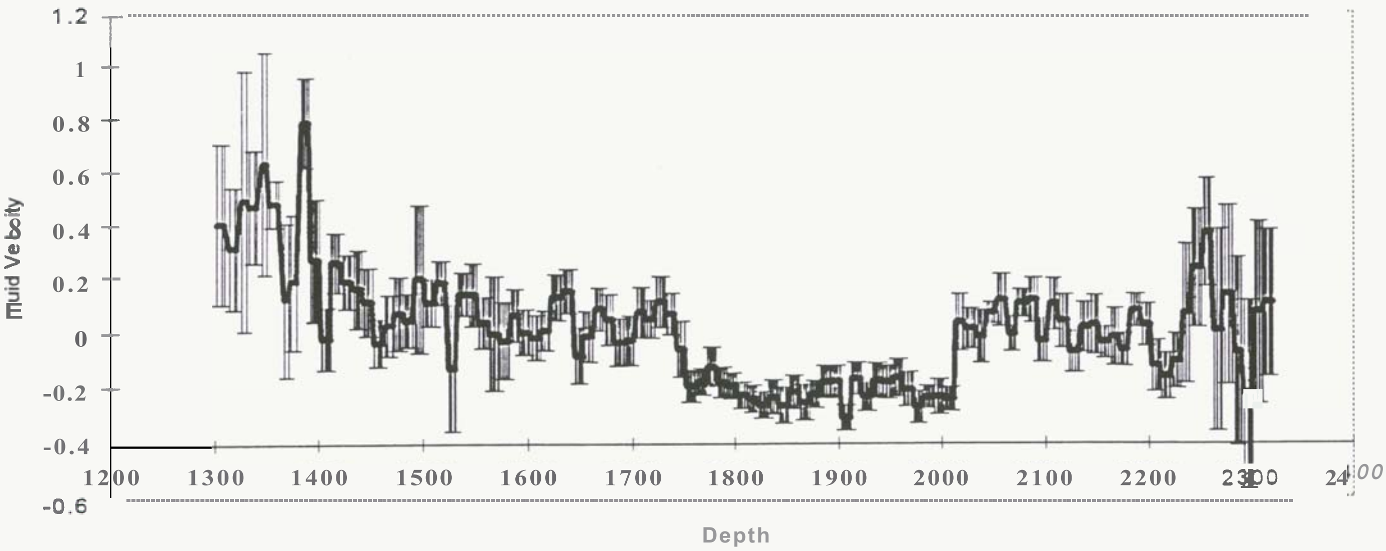

Figure 5. Fluid velocity profile, when suspect spinner data added, showing systematic error

. Inspection of figure 2 shows that run 2U is recording zero spin while the tool is ascending the lower segment of the well, against the direction of flow (if any). Such problems are common. They introduce an element of systematic error that is not allowed for in the standard errors. Such systematic error often exceeds the random noise in magnitude, as it did in this case.

4.2 Wellbore diameter

Sometimes wellbore diameter is inferred from spinner runs. In fact they do not yield such information. The spinner measures, in principle, fluid velocity and information about wellbore diameter is available only by inference from this.

Figure *6* below shows an example of such inference. The fluid velocity increases over the interval 1120-1230m, although taking account of the margin of error it could be asserted that the profile does not differ significantly from constant. Accepting that there is a consistent trend of increasing velocity with depth, the simplest explanation is that the wellbore is getting narrower with depth.

In principle, given two sets of velocity profiles at different **flow** rates, it is possible between them to obtain an unequivocal identification of the zones of fluid loss or gain. The remaining variation in fluid velocity can then be attributed to variations in diameter. However in practice the noise level is so great that this does not work.

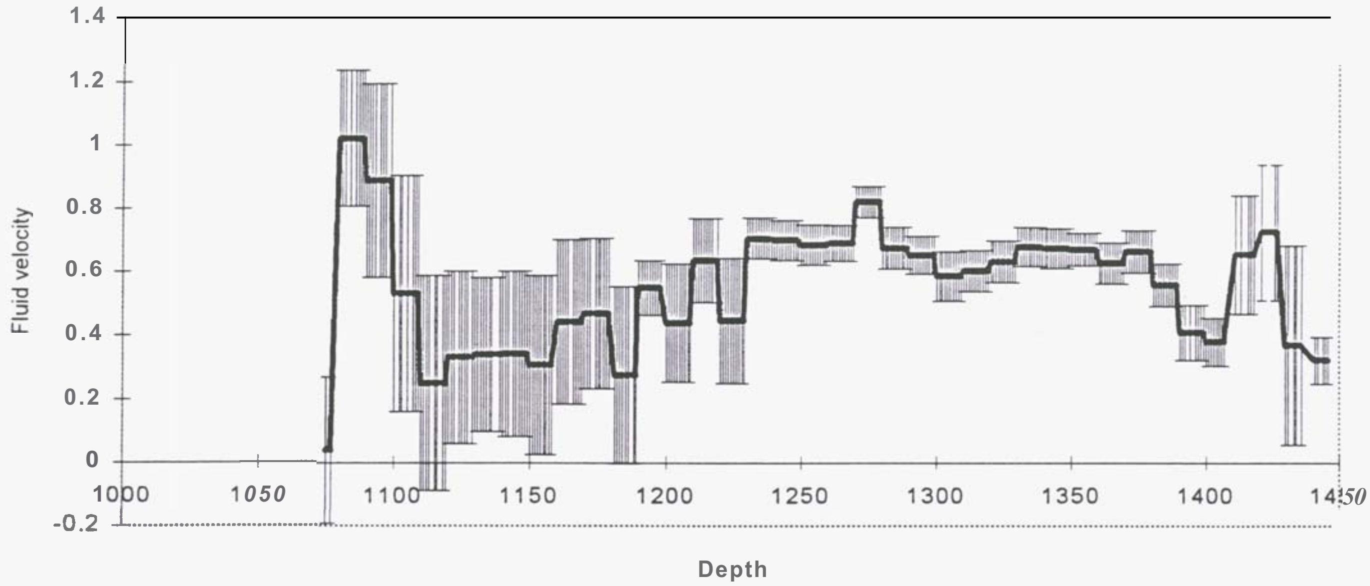

Figure 6. Fluid velocity profile, 1050-1450m, showing effect of wellbore diameter change

5. DISCUSSION

This approach to spinner interpretation has several advantages:

- It contains crossplotting and calibration as special cases within the more general method
- It simplifies interpretation by extracting from a large amount of noisy data the desired parameters
- It is less subject to subjective bias.

The simplification of the data is important. Given the large volume and noisiness of spinner data, reducing it to a velocity profile is very helpful. Doing so in an objective manner is even more helpful.

This method of analysis is simpler and more direct than crossplotting or calibrating the spinner separately, and more objective than visual analysis of the spin profile. It is thus both mathematically better technique and operationally easier.

In any analysis the spinner interpretation must also be constrained by temperature and pressure logs when these have been measured simultaneously.

ACKNOWLEDGMENT

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REFERENCES

Goranson, C., & J. Combs, 1995 "Characterisation of injection wells in a fractured reservoir using PTS logs, Steamboat Springs Geothermal Field, Nevada, USA" Proc. Stanford Workshop on Geothermal Reservoir Engineering.