The Feasibility of Acoustic Thermometry For Laser EDM Temperature Correction

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July 22, 1992

1 Introduction

The primary correction factor for laser Electronic Distance Measurement, EDM, is temperature[1,2,3]. The sensitivity of the speed of light in the atmosphere is approximately 1 ppm/°C, e.g., 100 μm/°C at 100 meters. This is a significant error for the GBT metrology requirements and therefore must be corrected or allowed for [1].

Our present plan is to use the measured distances between the ground–based ranging units as our "standard" distance. These measured distances will change as the local refractive index changes and will provide a scaling factor for the measured distances on the structure.

The GBT will be so large that significant additional corrections will be required, based on the height of the measurement path above the ground. We have assumed that the air both around and within the structure will conform to a well–behaved, predictable model, so that these additional corrections may be applied with sufficient accuracy. It may well be that this assumption is justified. Temperature sensors up the feed arm will certainly be helpful, but the fact is that we will not know until after the equipment is installed on the GBT.

This note describes a technique that seems to be able to provide information on the refractive index variation between measurement paths. A detailed possible application of the technique applied to the GBT will be given in a later note. Preliminary results only, are presented here.

2 Acoustic Thermometry

One potentially useful technique to measure the integrated temperature through a laser path is acoustic thermometry[4,5,6]. The speed of sound[7,8] is independent of pressure, and proportional to $T^{1/2}$, where T is absolute temperature. At normal ambient conditions, the sensitivity of the speed of sound is approximately 1700 ppm/°C. This combination of high temperature sensitivity, pressure insensitivity, and path length integration; makes acoustic thermometry an in-

[1] John Payne has pointed out that radio waves are also subject to the same effect, i.e., a temperature gradient in the dish will result in differential phase shifts at the receiver. This is an area that requires more analysis. For this report, we will assume a true geometric paraboloid is desired.

teresting area to investigate.

3 Experimental Results

Experimental work on acoustic thermometry was started at Green Bank this summer. Two summer engineering students, Steve Massey and Steve Riley, set up a simple speed of sound experiment in the field. This experiment was constructed with a minimum amount of equipment and operated in parallel with the laser system. The object was for the students to look at the feasibility of the method in the time allowed.

Two methods were explored for measuring the speed of sound. Both methods used a 20 Watt audio amplifier, horn speaker, and a parabolic microphone. The first method was to produce a continuous tone and look at the phase shift of the signal at the microphone. This was observed on an oscilloscope and displayed on a Clark–Hess phase meter. The initial results showed "noise" of around 1 °C. It was felt that this was too high and probably due to reflections from the ground.

The second method measured the time delay for a pulse produced by a step function input to the speaker. This method was used to avoid possible problems with reflections. The signal was input into a HP digital oscilloscope with an IEEE–488 interface. A BASIC program was written to detect the time delay of a signal edge on the oscilloscope. This experiment was operated to log the time delay and calculate the temperature.

The data in this report was obtained using the second method. It should be noted that the "noise" we were seeing in the phase measurement was probably a true representation of the dynamic atmospheric temperature, and not due to reflections as first thought!

The data included in this report is for a 47 meter path adjacent to a 50 meter laser path. Figure 1 is a 14 hour plot of the temperature measured inside a National Weather Service type instrument shelter (white louvered wood box) and the 47 meter acoustic temperature.

Figure 2 is a 14 hour plot of the same data showing the laser distance and acoustic temperature. Note the same "high frequency" character of the data. It should be noted that the laser and acoustic experiments were conducted on two independent computers that were not synchronized, so the data are not exactly matched in time.

Figure 3 is a plot of the laser distance vs acoustic temperature. Note that the measured slope of 39 μm/°C is close to the theoretical value.

Figure 4 is a plot showing the laser distance and acoustic temperature for data taken on 10 second intervals. Note the high correlation with temperature changes on the order of 1 minute! This strongly suggests that "high frequency" atmospheric induced errors in the laser data are in fact due to measurable temperature variations.

4 Future Work

Based on the encouraging results of the experimental data, it is felt that work should continue. The primary objective should be to improve the acoustic temperature measurement equipment and software in order to synchronize the laser data to the acoustic data, and improve the detection algorithm.

References

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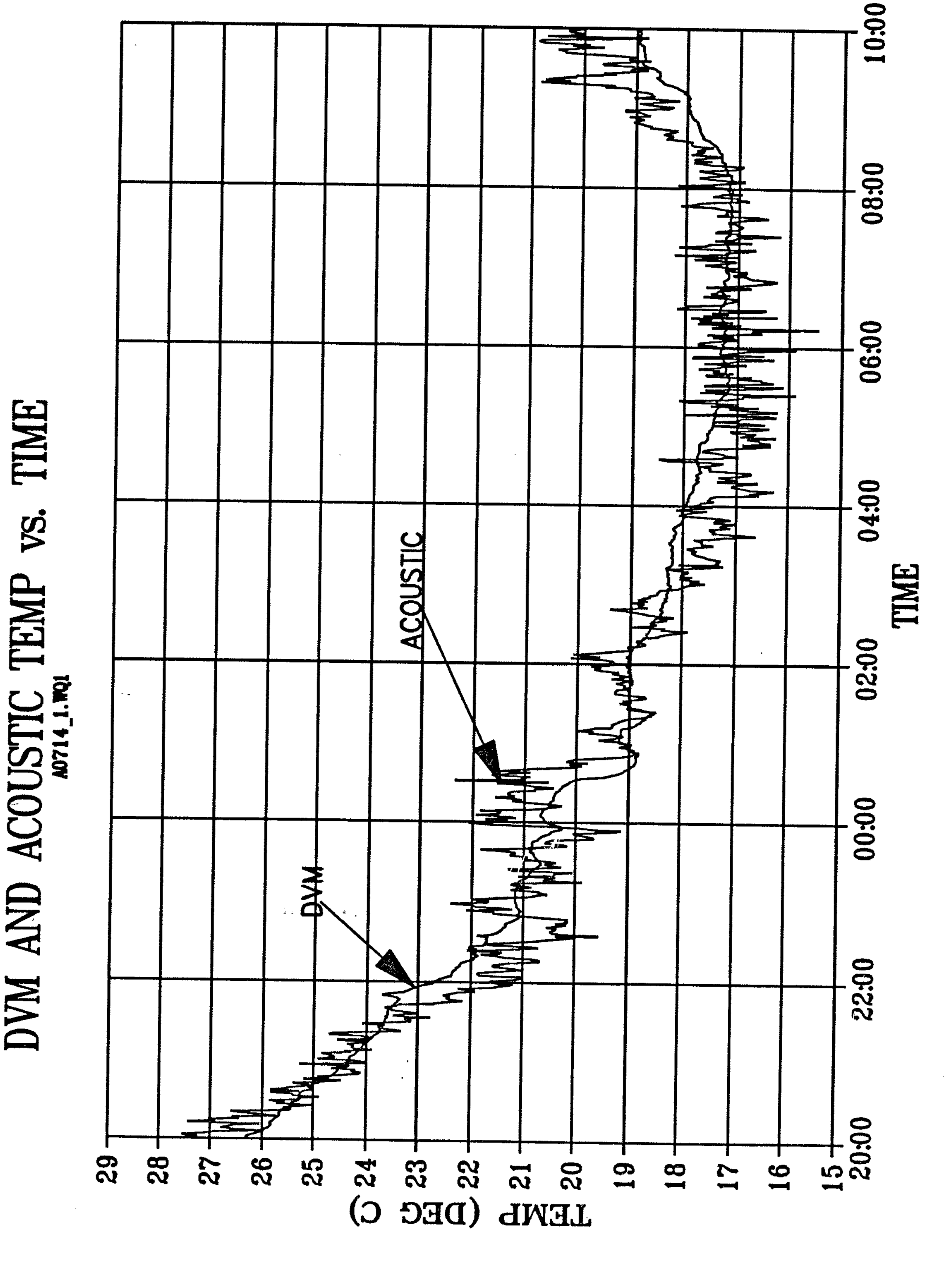


DVM AND ACOUSTIC TEMP vs. TIME
A0714_1.WQ1
DVM
ACOUSTIC
TEMP (DEG C)
TIME
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
20:00
22:00
00:00
02:00
04:00
06:00
08:00
10:00

Figure 1:

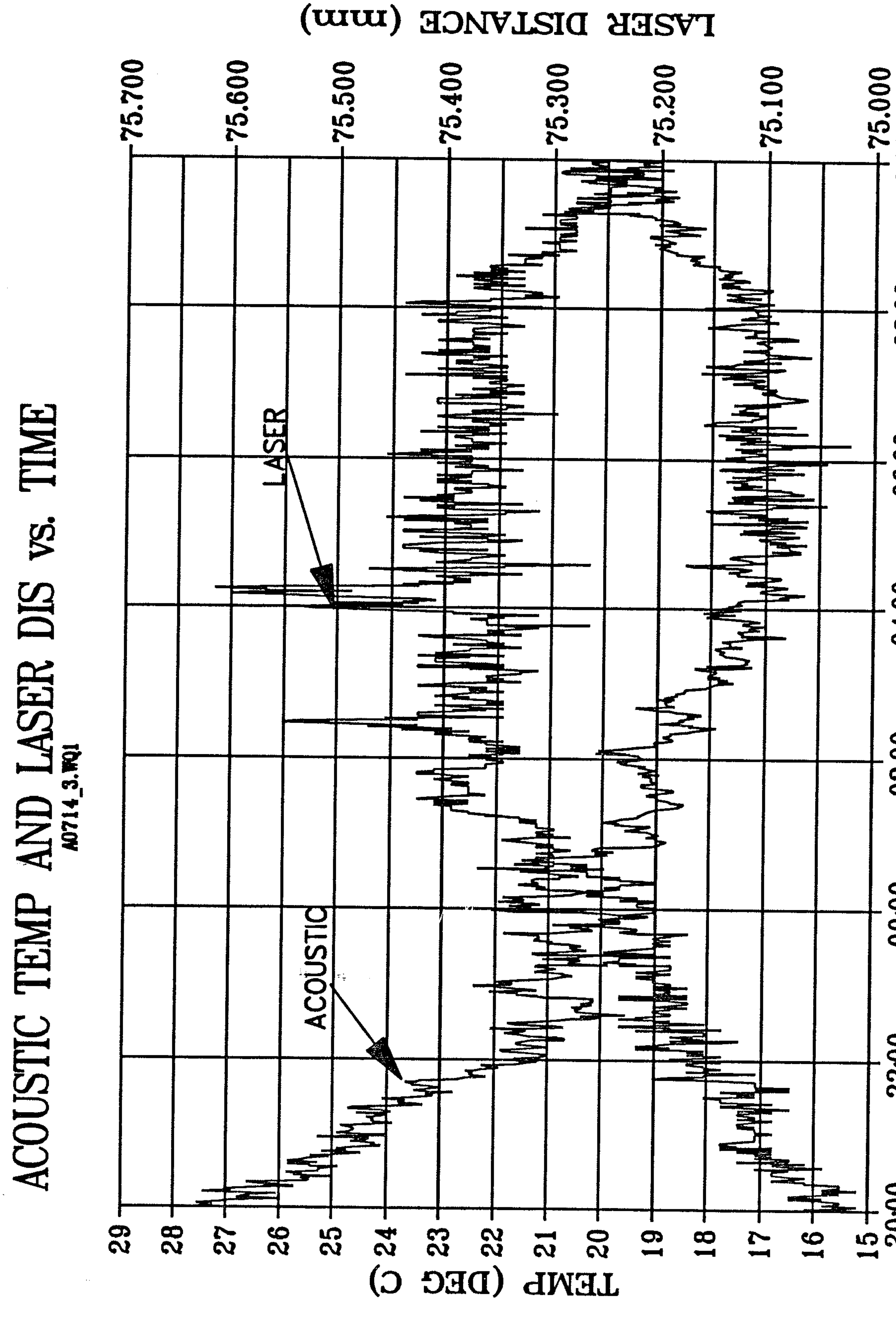

ACOUSTIC TEMP AND LASER DIS vs. TIME
A0714_3.WQ1
LASER
ACOUSTIC
TIME
TEMP (DEG C)
LASER DISTANCE (mm)
20:00 22:00 00:00 02:00 04:00 06:00 08:00 10:00
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
75.000 75.100 75.200 75.300 75.400 75.500 75.600 75.700

Figure 2:

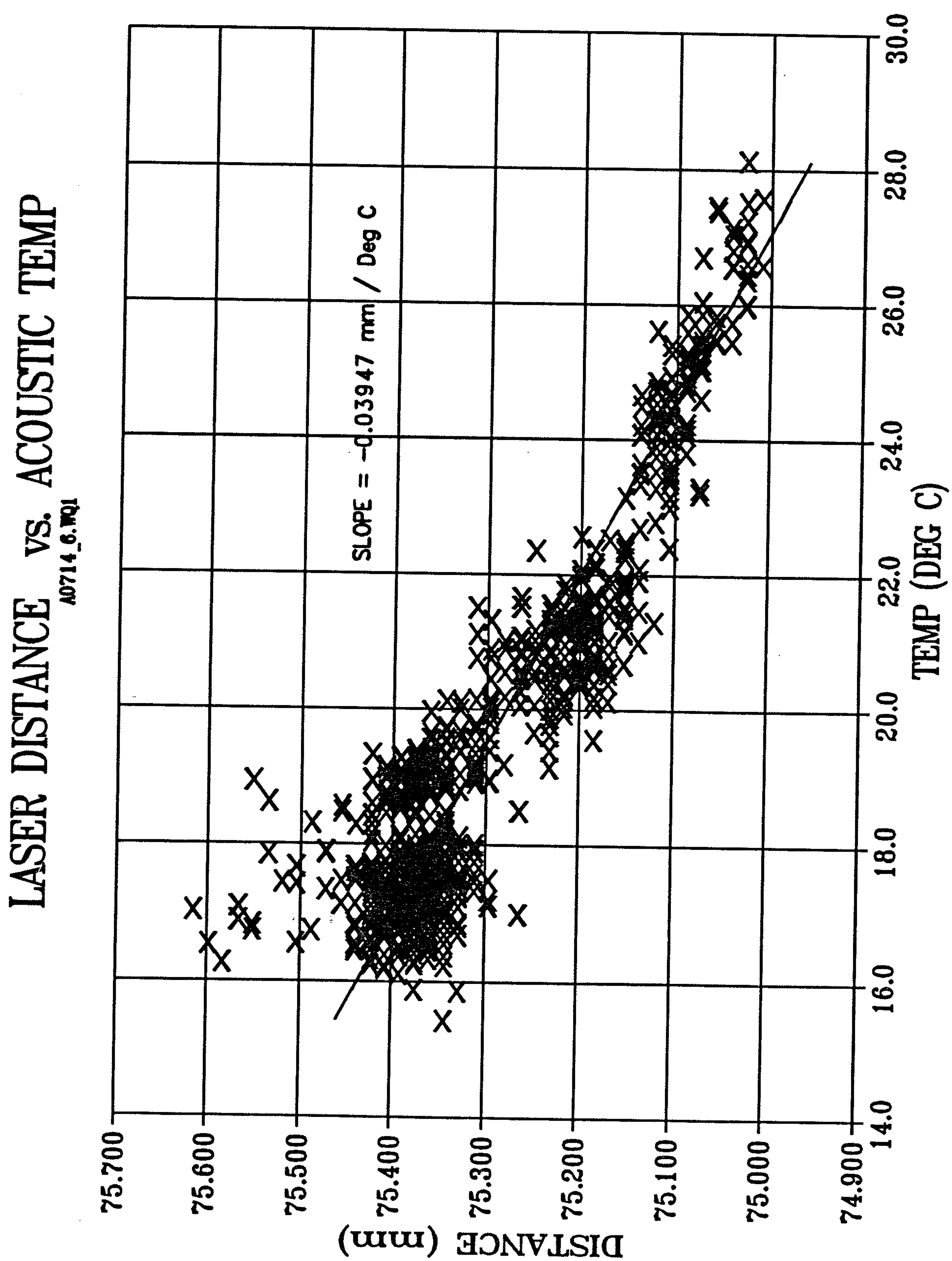
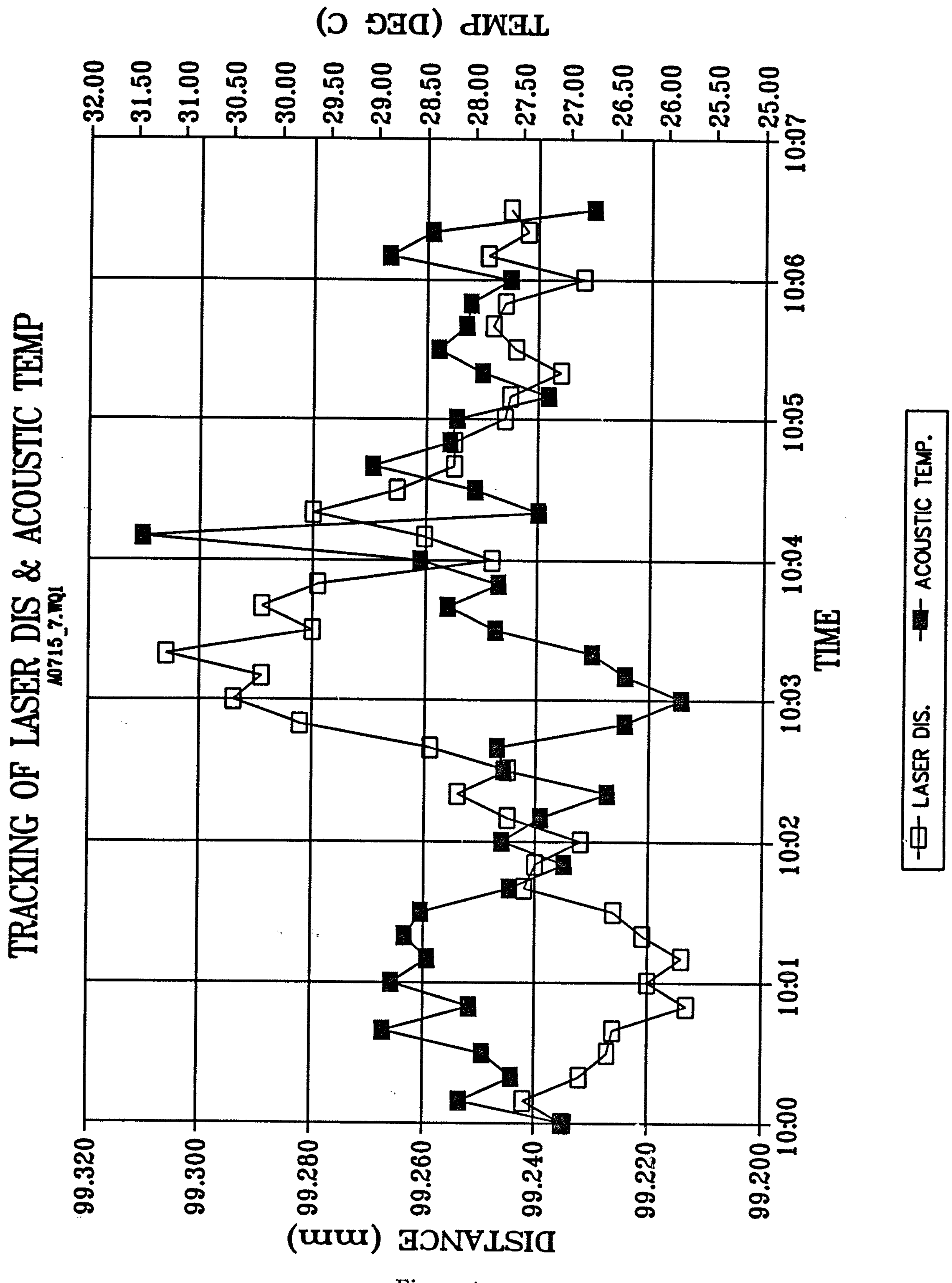

LASER DISTANCE VS. ACOUSTIC TEMP
A0714_6.WQ1
SLOPE = -0.03947 mm / Deg C
DISTANCE (mm)
TEMP (DEG C)
75.700
75.600
75.500
75.400
75.300
75.200
75.100
75.000
74.900
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0

Figure 3:



TRACKING OF LASER DIS & ACOUSTIC TEMP
A0715_7.WQ1
TEMP (DEG C)
32.00
31.50
31.00
30.50
30.00
29.50
29.00
28.50
28.00
27.50
27.00
26.50
26.00
25.50
25.00
DISTANCE (mm)
99.320
99.300
99.280
99.260
99.240
99.220
99.200
TIME
10:00
10:01
10:02
10:03
10:04
10:05
10:06
10:07
LASER DIS.
ACOUSTIC TEMP.

Figure 4: