Fermilab

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ESR Field Meter Measurement of SSC Magnets

Introduction

SSC requires large number of magnets to be measured in a short time. In the present plan, we would like to eliminate the cool test for most of the magnets. Electron spin resonance (ESR) method has a possibility of measuring magnetic field very accurately at low current without cooling it down.

Measurement methods based on rotating coil has been used in the past magnet developments. Though they would be still effective for the SSC measurement, an alternate method which uses ESR could show some advantages. It does not need any mechanical motion. It gives "absolute" result independent to the geometry of the probe. It measures localized field rather than the average over the length of the pick up coil. This note describes the first attempt to use ESR for SSC magnet field measurement[1] at Fermilab.

ESR and NMR

Magnetic moment, $\vec{\mu}$, with angular momentum behaves according to the equation:

$$\frac{d\vec{\mu}}{dt} = \gamma(\vec{H} \times \vec{\mu}) \tag{1}$$

under static magnetic field $\vec{H}$, where γ is a constant representing the gyromagnetic ratio. . This is written in a coordinate system rotating with angular velocity $\vec{\omega}$,

$$d\vec{\mu} = d'\vec{\mu} + \vec{\omega} dt \times \vec{\mu} \tag{2}$$

as:

$$\frac{d'\vec{\mu}}{dt} = (\gamma\vec{H} - \vec{\omega}) \times \vec{\mu} \tag{3}$$

*Distribution: R.Bossert, J.Carson, S.Delchamps, S.Gourlay, T.Jaffery, W.Koska, M.Kuchnir, M.Lamm, G.Pewitt, R.Sims, J.Strait, talk on MSIM, January 7, 1992.

[1]The work partly supported by Japan-U.S. collaboration fund.

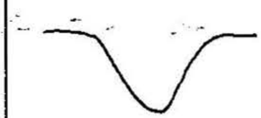
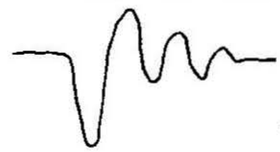
Obviously, the magnetic moment looks static if $\omega = \gamma H$. In the static coordinate system magnetic moment makes precession around the external field axis at the angular velocity ω. If a rotating field [2], H_1, with frequency $\nu = \omega/2\pi$ is applied perpendicular to the static external field, the magnetic moment rotates in the rotating coordinate system around H_1, which means the flipping of the magnetic moment in the static coordinate system. This happens only when the applied magnetic field frequency is the same as the precession frequency, hence this is a resonance between electro-magnetic field and spin state. Therefore $h\nu = \gamma h H/2\pi$ should correspond to the energy gap of the spin state, $g\mu H$ in quantum theory. Differnce of electron mass and proton mass makes a three digit differnce in the resonance field at the same frequency.

Observation of the phenomena can be made measuring the Q of a tank circuit which contains a sample under external field. A solution of detailed equation of motion made by Bloch gives the imaginary part of the susceptibility, χ'', at angular frequency ω as

$$\chi'' = \frac{\gamma T_2 M_0}{1 + (\omega - \gamma H)^2 T_2^2}, \tag{4}$$

where T_2 is the spin-spin relaxation time constant and M_0 is the static magnetization. Since electron spin has much larger M_0 and much shorter T_2, it can have very large signal compared to that of NMR. On the other hand, the shorter T_2 caused by the long range dipole interaction between spins makes the resonance signal more broad. The absolute accuracy of the measurement becomes less easy because of this fact. Dipole broadening of the ESR signal is so large as to make it almost useless for field measurement. But in some chemical compounds which have overlaps in electron wave function have moderately longer T_2 because of the exchange of electrons. Crystalline organic radicals such as diphenyl picryl hydrazyl (DPPH) are the typical m iterial which are relatively stable in this kind. Although ESR signal has line width of a few tenth of gauss, the clear line shape without wiggle makes it possible to define the center of resonance by electronics. The comparison between ESR and NMR is summarized in the following table.

[2] An oscillating field is considered to be a combination of two rotating field in opposite direction.

	ESR	NMR
resonance frequency	$h\nu = g_e \mu_B H$	$h\nu = g_N \mu_N H$
magnetic moment	$\mu_B = \frac{eh}{4\pi m_e}$ 0.92732×10^{-23}	$\mu_N = \frac{eh}{4\pi m_P}$ 0.50504×10^{-26}
useful sample	DPPH 2804.424 kHz/G	H_2O 4.257608 kHz/G D_2O 0.653569 kHz/G
relaxation time	$T_2 \sim 10^{-8} sec$	$T_2 \sim 10^{-4} sec$
signal form		
view modulation	10Hz	30 Hz
practical modulation	10kHz field modulation for PSD lock	10 kHz frequency modulation for PSD lock

Measurement Equipment

The measurement equipment for ESR observation meter consists of voltage controlled rf oscillator, amplifier, phase sensitive detector, and a probe which has a tank circuit, modulation coil and sample. A viewing oscilloscope and a frequency counter is necessary to measure the field. A set of type EFM-30AX ESR field meter fabricated by Echo Electric was brought from KEK to Fermilab as a part of collaboration program. This field meter uses DPPH ($g = 2.0036$)as the sample and the sample size is about 5 mm cube. The probe measures $10mm \times 20mm$ in cross section.

Field meter was connected through EIG-488A unit ,o a HP98563 computer[3] called MLT2 on the network address 131.225.45.12. A HP3457A DVM and a shut was used to measure the current during the measurement. A current of about 4 A was given to the magnet using Kepko BOP72-6M as power supply.

Initial Measurement Results

Fig.1 is the first measurement made in model magnet DSA324 which had a curious transfer function change over the length observed at low temperature. Though the measurement was rough and especially had difficulty in maintaining constant current in the magnet, it was possible to see the collar package periodicity of the magnet and the location of the pressure gauge.

[3]Software under development by Donna Kubik

Application for long dipole magnets were attempted in DCA317 collard coil and DCA316 yoked coil. Fig2 and Fig3 are the results of the measurement. Field shape at the end part looks different from that of model magnet. Reproducibility of the measurement was good to the 6th digit as shown in Fig4.

The power supply was found to be able to supply current stably after a long warm ups if we do not use the external controller of the current. The major source of the fluctuation comes from the noise of the current measurement. Fig4 shows the measurement made for 1 hour at the same position.

These measurement accuracy may be good enough to measure the integration field of the magnet at room temperature. The problem for the collared coil is that the measurement is sensitive to the irons in the environment. Fig 5 is an example of the crane pass over the magnet with nothing hanged.

Measurements for yoked magnet is shielded from external objects but has the effect of hysteresis of the yoke. Fig6 is the measurement results with different polarity of current. Enlarged view in Fig.7 shows the hysteresis is as large as in the 4th digit. If the magnet is measured after cold test the magnet is expected to have about 7 gauss of magnetic field without current.

Conclusion

The use of ESR in the measurement of SSC magnets was attempted in success. To make this measurement really useful, it is necessary to establish the transporter of the device in the magnet. A corelation study between warm measurement and cold measurement has to be made in a hurry.

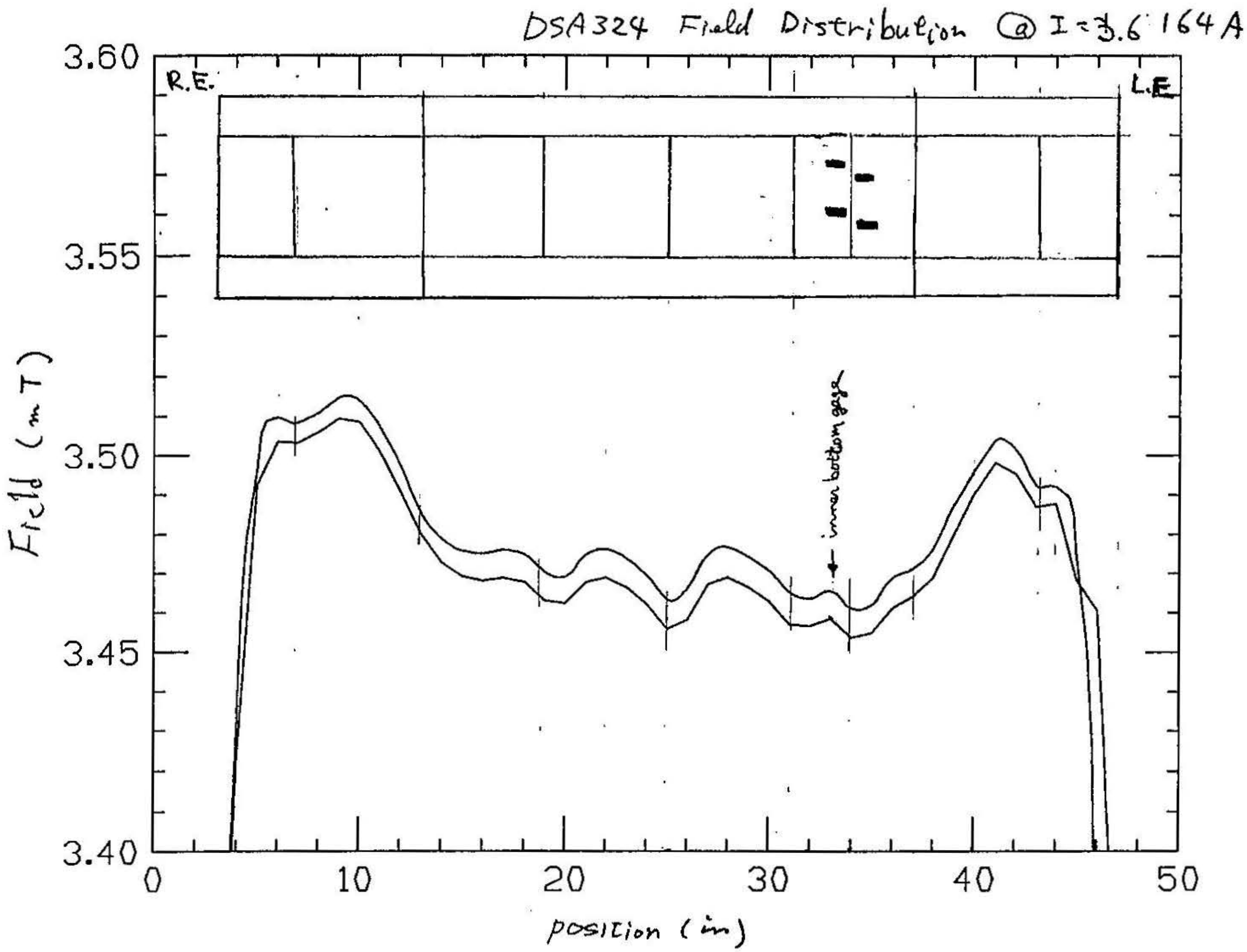

DSA324 Field Distribution @ I=3.6 164A
R.E.
L.E
inner bottom gage
Field (mT)
position (in)
3.60
3.55
3.50
3.45
3.40
0
10
20
30
40
50

Fig 1

Fig 1

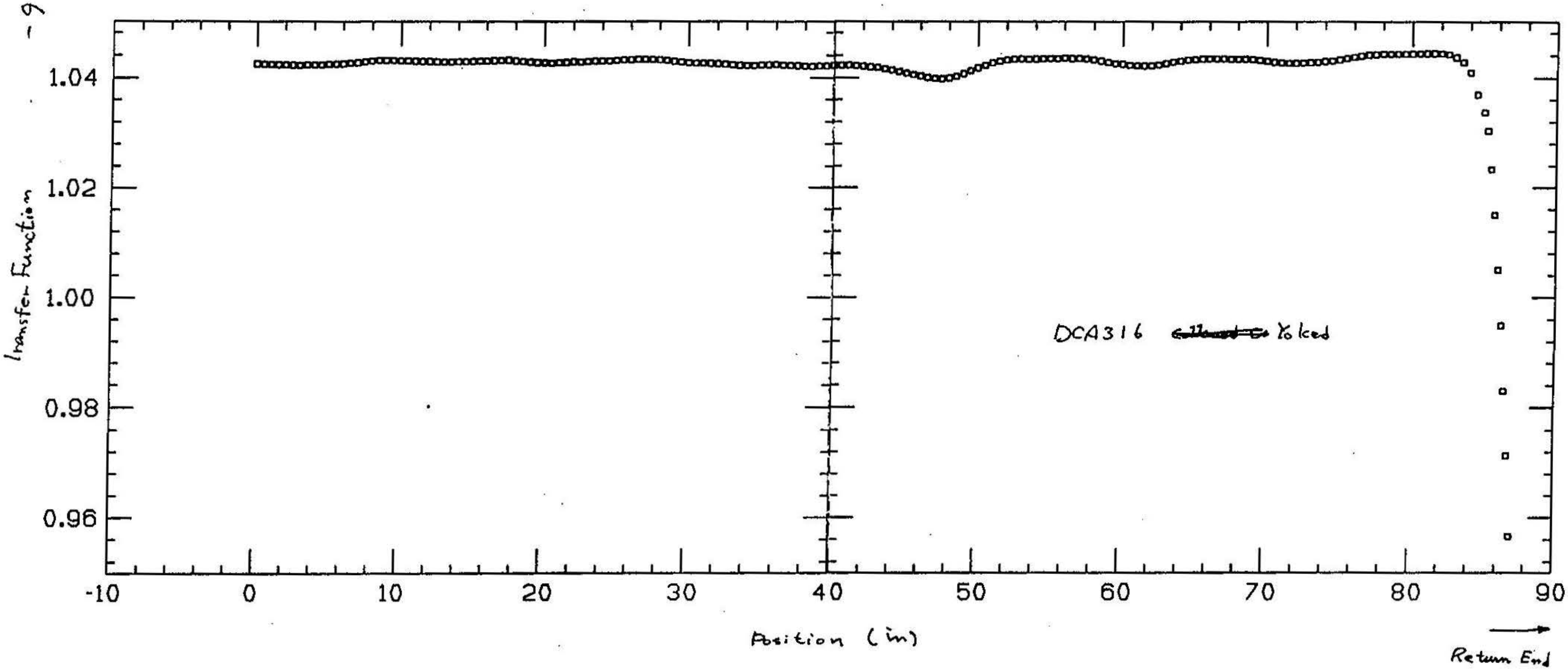
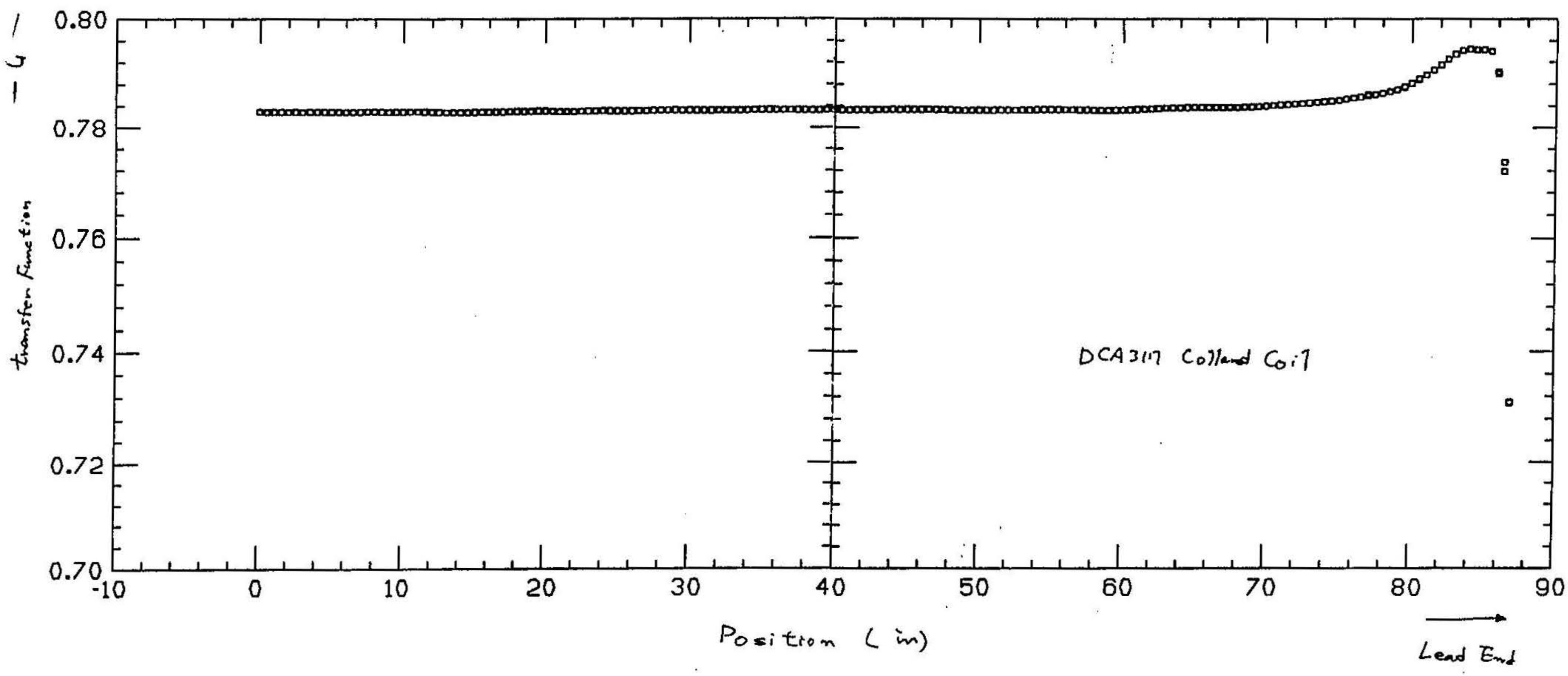
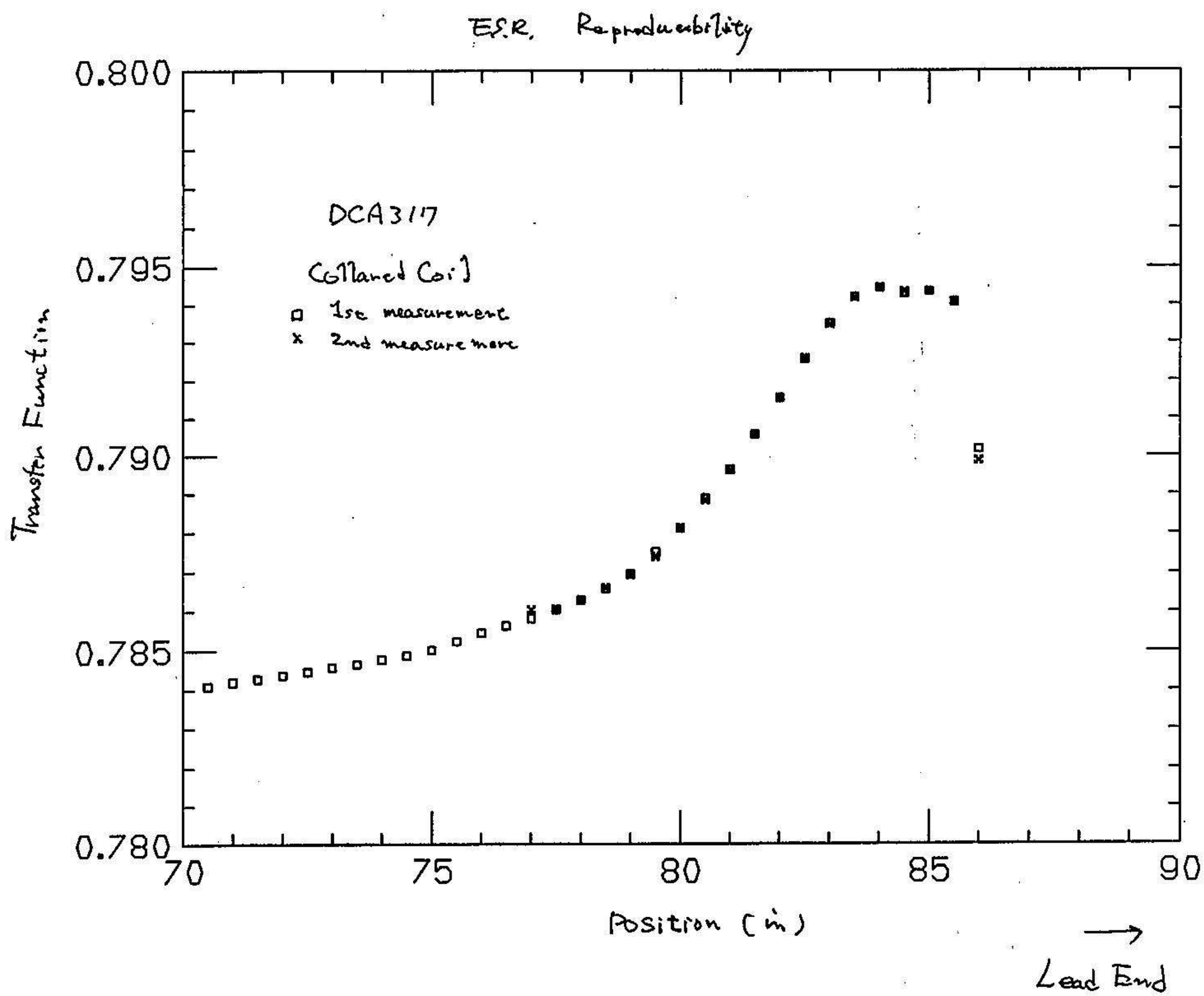

Transfer Function
1.04
1.02
1.00
0.98
0.96
-10
0
10
20
30
40
50
60
70
80
90
Position (in)
DCA316 Yoked
Return End

Fig 2



transfer function
0.80
0.78
0.76
0.74
0.72
0.70
-10
0
10
20
30
40
50
60
70
80
90
Position (in)
DCA317 Collared Coil
Lead End



E.S.R. Reproducibility
DCA317
Collared Coil
1st measurement
2nd measurement
0.800
0.795
0.790
0.785
0.780
70
75
80
85
90
Transfer Function
Position (in)
Lead End

Fig 4

Signal Fluctuation

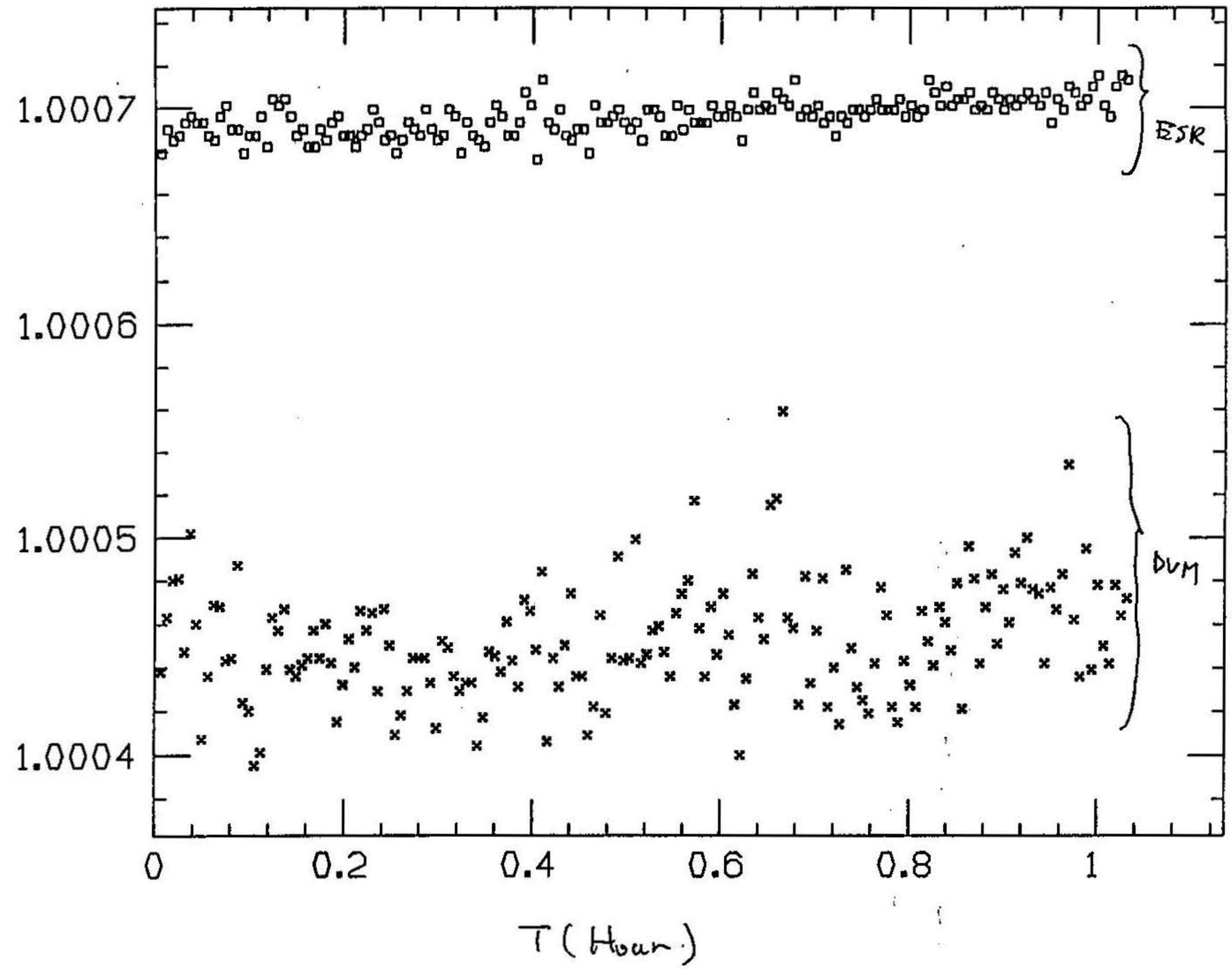


Fig 5

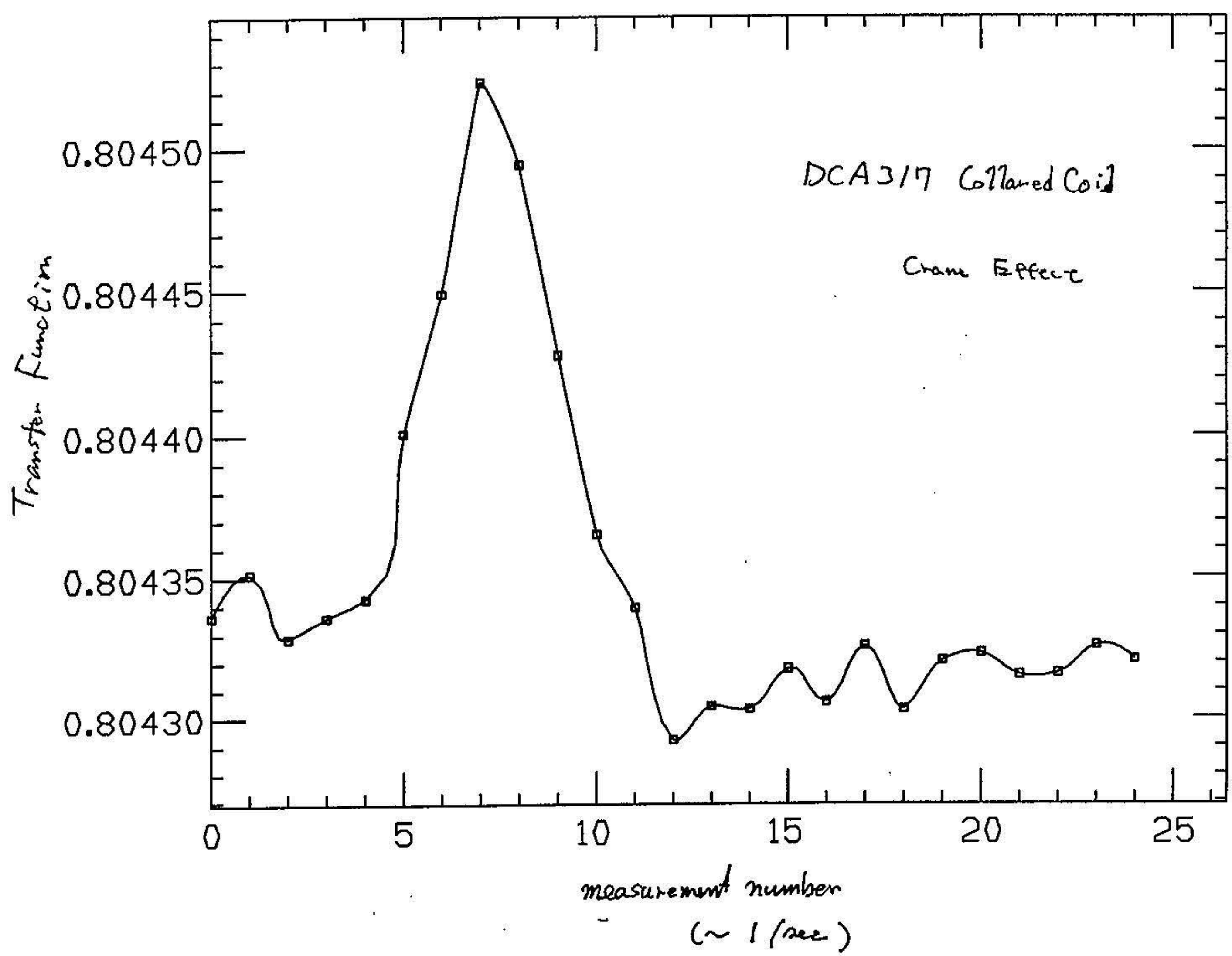

DCA317 Collared Coil
Crane Effect
Transfer Function
0.80450
0.80445
0.80440
0.80435
0.80430
0
5
10
15
20
25
measurement number
(~ 1/sec)

Fig 4

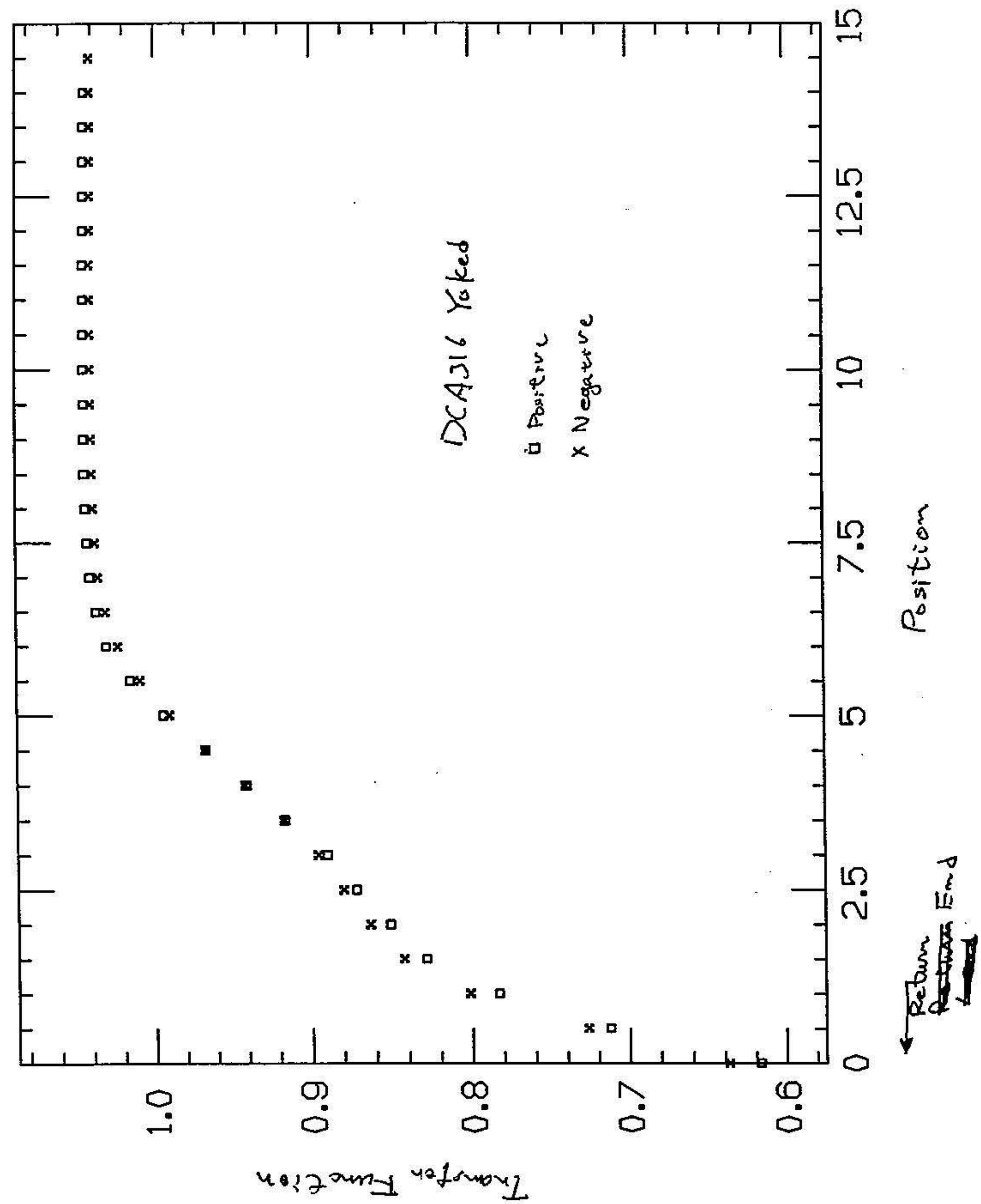

DCAJ16 Yoked
□ Positive
x Negative
Position
Transfer Function
Return End
0
2.5
5
7.5
10
12.5
15
0.6
0.7
0.8
0.9
1.0

Fig 6

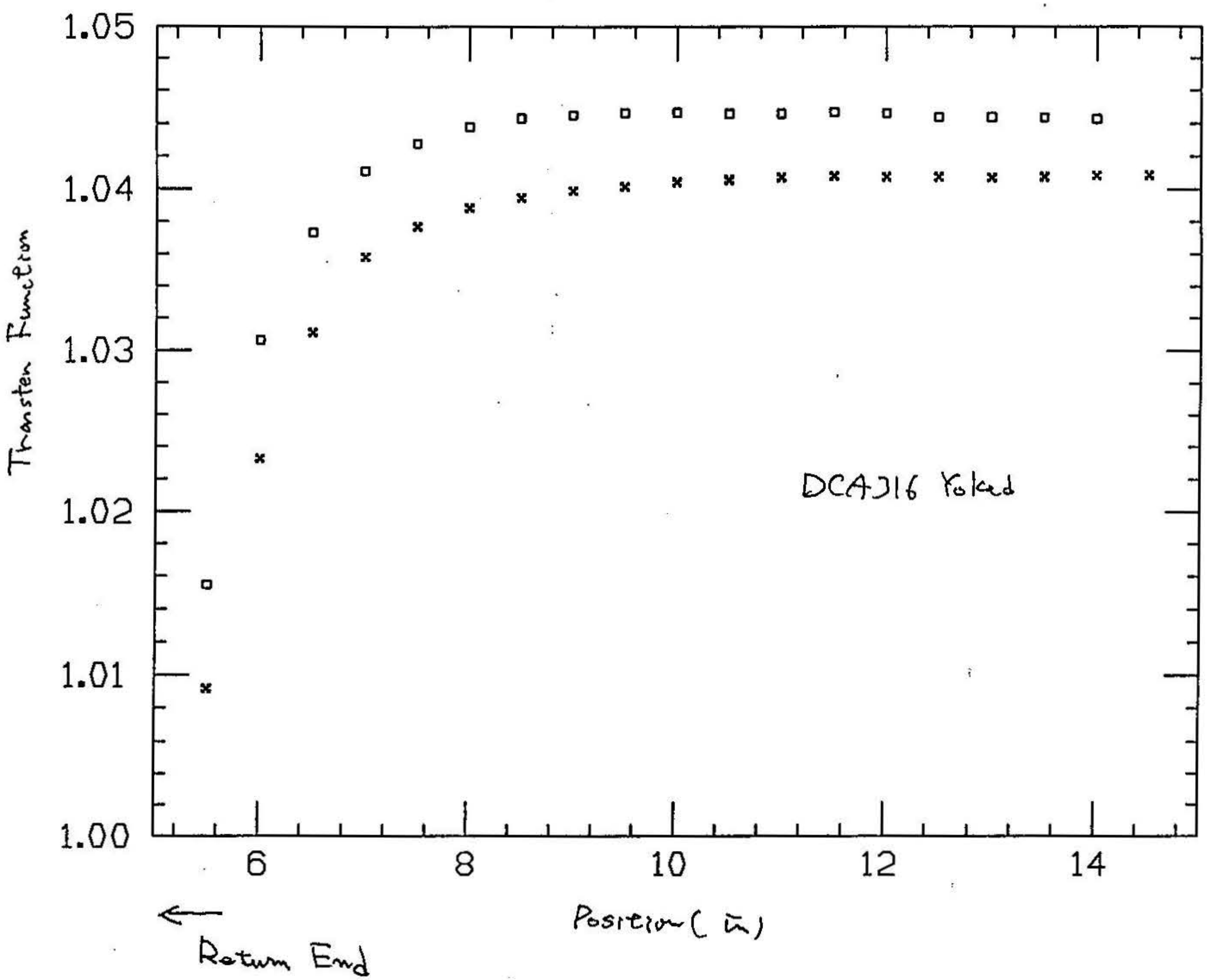

1.05
1.04
1.03
1.02
1.01
1.00
Transfer Function
6
8
10
12
14
Position (in)
DCA316 Yoked
Return End

Fig 7