

# A Proposal for Using Wire-Scanners at the LFNAC Test Facilities

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## Abstract

A proposal is made for using LEP type wire-scanners to measure the emittance (beam width) at the end of the TTF and S-Band Test LINACs. The LEP wire scanners are shown to satisfy all of the requirements for the measurement.

## Introduction

A fatal problem in measuring the emittance (beam width) of the accelerated LFNAC beam is the small beam size in combination with a high current. No foils, screens or harps will survive in the beam at the design current. Wire scanners provide a way to determine the emittance with a very good resolution also at design current.

In this proposal the following basic TTF and S-Band parameters are assumed:

<u>Parameter:</u>	<u>TTF</u>	<u>S-Band</u>
Beam width at the scanner (x, y): $2\sigma$	400 $\mu\text{m}$	1 mm
Number of electrons/bunch: $N_b$	$1.6 \cdot 10^8$	$3 \cdot 10^{10}$
Bunch repetition frequency: $F_b$	216.7 MHz	62.5 MHz
Length of the macro pulse: L	800 $\mu\text{s}$	2 $\mu\text{s}$
Pulse frequency: $F_p$	10 Hz	50 Hz
Number of electrons/macro pulse: $N_p$	$2.8 \cdot 10^{13}$	$3.75 \cdot 10^{12}$

## Desired wire-scanner parameters

1) The emittance  $\epsilon$  of the beam is proportional to the square of the beam size, therefore errors in the measurement of the size is a significant contribution to errors in emittance. A resolution of about 10  $\mu\text{m}$  is proposed for the measurement of the beam dimensions.

2) Depending on the method used to measure the beam parameters  $\epsilon$ ,  $\beta$  and  $\gamma$  one needs 1-3 scanners per direction (horizontal and vertical). Mounting two wires on a single fork in 45° "L" shape gives a method to measure both transverse dimensions with one scanner. The required speed of the scanner then has to be increased by a factor  $\sqrt{2}$  to reach the desired speed per direction.

3) During a scan, a part of the wire will be heated by the energy loss  $dE/dx$  of the electrons. The energy loss/electron  $dE/dx$  is 4.03 MeV/cm/electron for carbon. The resulting maximum wire temperature  $T_{\text{max}}$  depends on the LFNAC parameters and on the scanning speed  $v$ ; and can be estimated

:

$$T_{\text{max}} = 3.8 \cdot 10^{-14} \cdot dE/dx \cdot d \cdot N \cdot F / (c_p \cdot G \cdot v)$$

with:

$$1 \text{ MeV} = 3.8 \cdot 10^{-14} \text{ cal}$$

wire diameter:  $d$  (e.g. 7  $\mu\text{m}$  carbon; 34  $\mu\text{m}$  carbon; 10  $\mu\text{m}$  beryllium; 30  $\mu\text{m}$  quartz; ...)

Specific heat capacity:  $c_p = 0.283 \text{ cal}/(^{\circ}\text{C g})$  (carbon wire used at HERA)

Weight of the heated portion of the wire:  $G = 2 \sigma d \rho$

Density of the wire:  $\rho = 1.97 \text{ g/cm}^3$  (carbon wire used at HERA)

$N$  and  $F$  depend on the 'mode' of the scan, which depends on the required speed of the wire.

Note that the maximum temperature does not depend on the wire diameter  $d$ . The emission of secondary particles will reduce  $T_{\text{max}}$  by up to 70%. This effect is best left out of the calculation of  $T_{\text{max}}$  and included as a safety factor. Also radiation cooling and heat transport are not taken into account. The heat dissipates slowly from the wire due to the small surface area and diameter of the wire (Ref. 4).

We distinguish between two scanning modes:

1. Fast scan:

The wire crosses the beam within one macro pulse. The speed of the wire is then given by

$$v_{\text{fast}} = 2\sigma/L \text{ and } N = N_b ; F = F_b.$$

In case of TTF  $v_{\text{fast}}$  is 0.5 m/s. With this high speed, there must be a precise synchronisation between the position of the wire and the beam, and the pulse time for that the wire will meet the beam. With a speed  $v_{\text{fast}}$  of 1 m/s the synchronisation jitter can be of the order of  $\Delta t = 100 \text{ } \mu\text{s}$ . This means, that the reproducibility of the scans have to be not worse than  $\Delta t$ . The resulting maximum temperature  $T_{\text{max}}$  is 2380 °C, which is well below the melting point of carbon (3500 °C. In case of the S-Band test facility  $v_{\text{fast}}$  is 500 m/s which is not feasible.

2. Slow scan:

A second possibility is to scan the LINAC beam in small steps of about 10  $\mu\text{m}$ /macro pulse:

$$v_{\text{slow}} = 10 \text{ } \mu\text{m} \cdot F_p \text{ and } N = N_p ; F = F_p.$$

For the TTF this results in 40 data per  $2\sigma$  which is enough for a good quality measurement within the required resolution. The speed of the wire is then  $v_{\text{slow}} = 0.1 \text{ mm/s}$ . The maximum temperature of the wire will be  $T_{\text{max}} = 6.9 \cdot 10^{-9} \text{ } ^\circ\text{C/electron}$ . The maximum number of electrons is then about  $5 \cdot 10^{11}$  electrons/macro pulse or 2.5% of the design current.

At the S-Band test facility the speed  $v$  is 0.5 mm/s (100 data per  $2\sigma$ ) and  $T_{\text{max}}$  results in  $1.85 \cdot 10^{-9} \text{ } ^\circ\text{C/electron}$  which allows a measurement at 50% of the design current. With 20  $\mu\text{m}$  steps (50 data per  $2\sigma$ ;  $v = 1 \text{ mm/s}$ ) one can measure the beam width at design current.

Nevertheless, the slow scan provides a very sensitive measurement also at very low currents which may be important in the setting up phase of the LINACs. With a fast gate the slow scan gives the possibility to measure the width of bunches at a certain position in the macro pulses.

In conclusion the scanner have to provide a spatial resolution of about 10  $\mu\text{m}$  and it has to run with a speed ranging between  $v_{\text{slow}} = 0.1 \text{ mm/s}$  up to  $v_{\text{fast}} = 1 \text{ m/s}$ . The timing of the fast scans has to be reproducible within an uncertainty of about 100  $\mu\text{s}$  to be synchronous with the macro pulse (TTF).

### The LEP wire scanner

A sketch of the LEP wire scanners shown in Fig. 1. It is driven by a DC Motor which can be programmed to run with a defined speed, up to a few m/s. The LEP scanner is run

with a maximum speed of 1 m/s but with some improvements just tested at CERN a maximum speed of 2 m/s is expected (Ref. 1).

The position of the wire can be measured in two ways, by an optical ruler and by a linear potentiometer. The optical ruler which is used at LEP provides a resolution of 4  $\mu\text{m}$  (Ref. 2). Fig. 2 shows a schematic drawing of the ruler. The maximum speed of the ruler is specified as 1m/s (data sheet, see Fig. 3) but speeds of up to 5 m/s are possible (Ref. 3). The optical part of the ruler is sensitive to radiation damage, and so it must be protected against synchrotron radiation (Ref. 1). In the case of the LINACs, this can easily be done with few millimetres of lead. The potentiometer can run with a speed up to 10 m/s and a resolution of 2  $\mu\text{m}$  is possible (data sheet, Fig 4). No radiation damage has been observed up to now.

Because it is used in a circular machine no measurements have been done to determine the reproducibility of the timing of the LEP scanner. In private discussions, the authors of Ref. 4 claim that the trigger-requirements for the TTF (fast scan) can be satisfied by the LEP scanner. Timing studies have been done with an other scanner with a comparable DC motor: The very fast (20m/s) PS - wire scanner. Fig. 5 gives an estimate of the behaviour of the DC motor as a function of the driving voltage U. The figure shows, that the scanner acts very prompt ( $<500 \mu\text{s}$ ) to the driving voltage. A feedback loop is used to ensure that the scanner will move as programmed (Ref. 4).

A major problem in using wire scanners in electron accelerators is the electromagnetic heating of the wire which may destroy the wire even in its parked position. The LEP group has accumulated a lot of experiences studying this problem. Using the rugged ceramic fork constructed for the HERA wire scanner in the LEP scanner mechanism will reduce the problem considerably. Tests are in preparation at CERN. Nevertheless, this kind of problem is present with every wire scanner.

The mechanical components of the LEP scanner cost about 25000 SFr/scanner (Ref. 1) without assembly. The finished product looks very professional. Nearly no additional development work is necessary should we copy the scanner. The LEP crew with their large experience, is glad to help us with the mechanical part as well as with the electronics and with the software (Ref. 1). The steering and the readout of the monitor is completed and well tested (by the LEP group) during the last two years. A prototype of the scanner is available from CERN.

#### Read out

There are two ways to measure the LINAC beam profile using a wire scanner: In dependence of the wire position 1) measuring the amount of high energy particles (mostly bremsstrahlungs-photons and scattered electrons) coming from the interaction of the wire with the beam using a scintillation counter and 2) measuring the current in the wire which results from secondary particle emission. The first method is very sensitive and is preferred. The second method enables one to calculate the temperature of the wire and to look for broken wires by measuring the resistance of the wire. The profile measurement is strongly affected by thermal emission of electrons at high wire temperatures.

### Conclusions

Most of the required parameters of a wire scanner at the LINACs, e.g. speed and resolution, are satisfied by the LEP scanner. Some tests are necessary to check the reproducibility of the timing, necessary for fast scans. These tests can be done at CERN with their scanner test-stations. For the assembly and set-up (hard and software) of the scanners one can profit by the large experience of the LEP crew. Electronics and software for steering and readout are available from CERN. To install the scanner a technician, an electronic engineer and a programmer are needed. The work can be finished in roughly one year.

### Acknowledgement:

Many thanks to Mark l'Homme per Ski for his very useful comments to this manuscript.

### References:

- Ref. 1) R. Jung; CERN, private communication
- Ref. 2) B. Bouchet et al.; Wire Scanners at LEP  
Proc. Part. Accel. Conf. 1991, San Francisco
- Ref. 3) Hr. Lammers, Fa. Haidenhain, private communication
- Ref. 4) J. Camas, G. Crockford, G. Ferioli, C. Fischer, J. Gras, R. Jung, J. Koopmann,  
J. Mann;  
High Resolution Measurements of Lepton Beam Transverse Distributions with the  
LEP Wire Scanners  
Proc. Part. Accel. Conf. 1993, Washington D.C.
- Ref. 5) Ch. Steinbach, M. van Rooij; A Scanning Wire Beam Profile Monitor  
CERN/PS 85-33 (1985)
- Ref. 6) Brochure Fa. HEIDENHAIN: NC - Längenmeßsysteme

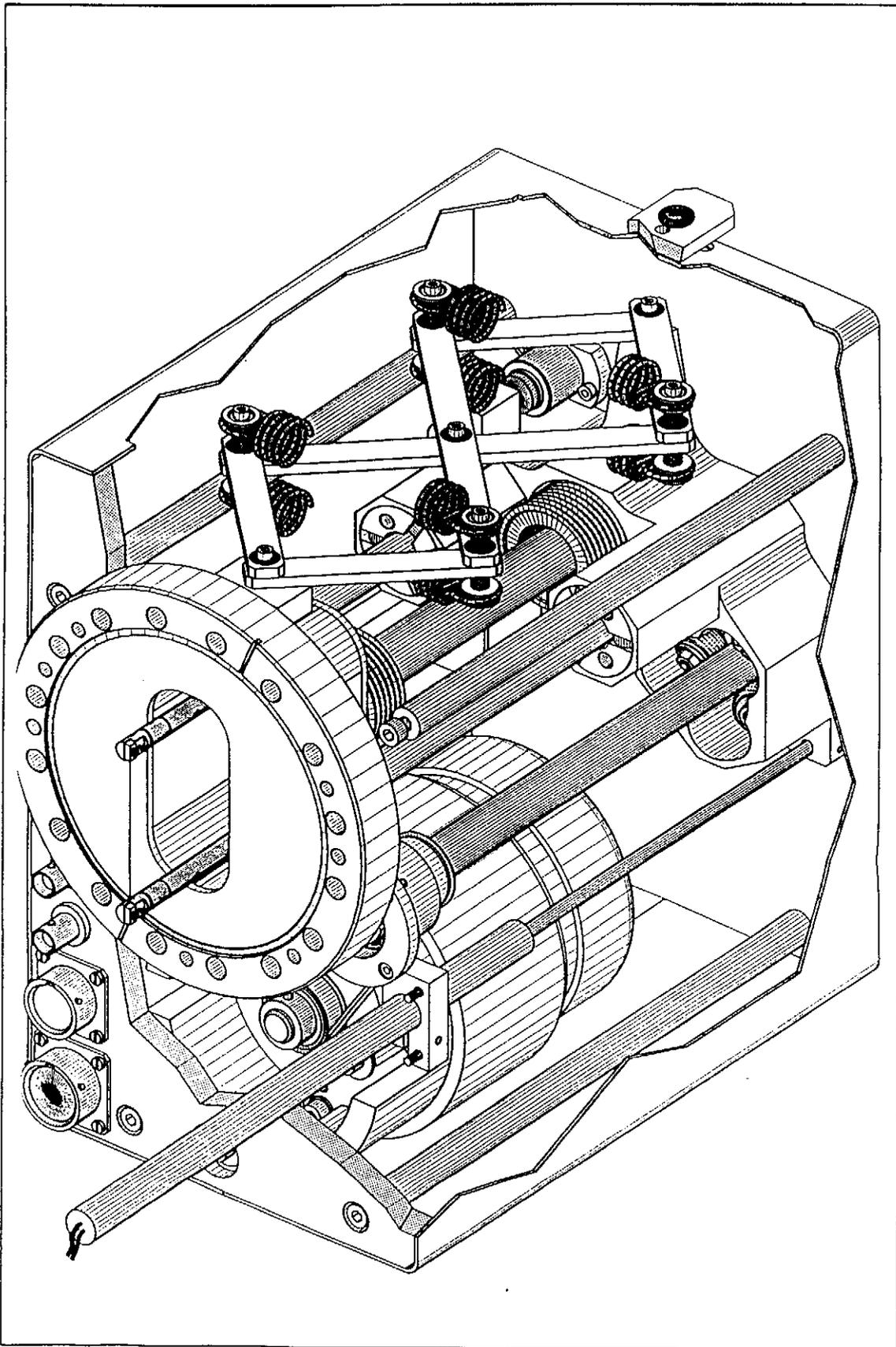


Fig. 1) The LEP wire scanner (Ref. 1)

HEIDENHAIN-Längenmeßsysteme der Bauform LS und LID enthalten einen Glasmaßstab mit einer im DIADUR-Verfahren aufgetragenen Strichgitter-Teilung. Das Gitter besteht aus lichtundurchlässigen Strichen und lichtdurchlässigen Lücken gleicher Breite. Eine oder mehrere Referenzmarken befinden sich auf einer zweiten Spur. Die Abtasteinheit umfaßt eine Lichtquelle, einen Kondensator, der die Lichtstrahlen parallel ausrichtet, die Abtastplatte mit den Abtastgittern und Silizium-Photoelemente.

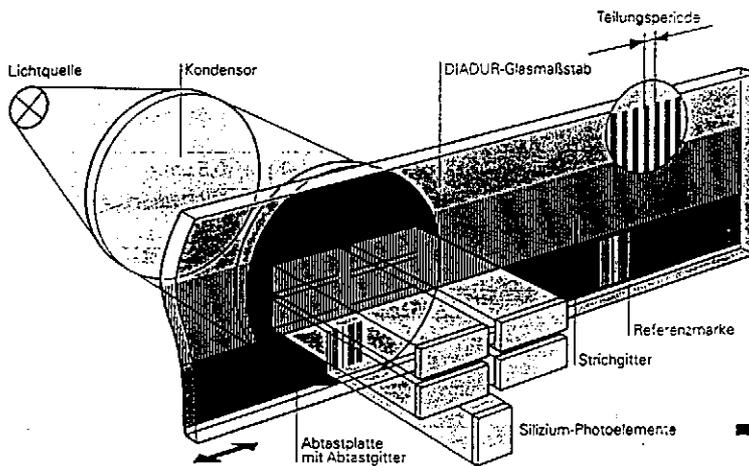
Bei einer Bewegung des Maßstabs relativ zur Abtasteinheit kommen die Striche und Lücken des Maßstabs abwechselnd mit denen der Abtastgitter zur Deckung. Die Photoelemente setzen den sich periodisch ändernden Lichtstrom in elektrische Signale um. Als Ausgangssignale stehen die beiden sinusförmigen Signale  $I_{e1}$  und  $I_{e2}$  und das Referenzmarkensignal  $I_{e0}$  zur Verfügung. Die Signale  $I_{e1}$  und  $I_{e2}$  sind um  $90^\circ$  el. zueinander phasenverschoben.

Signalgröße der Abtastsignale bei Last  $1\text{ k}\Omega$

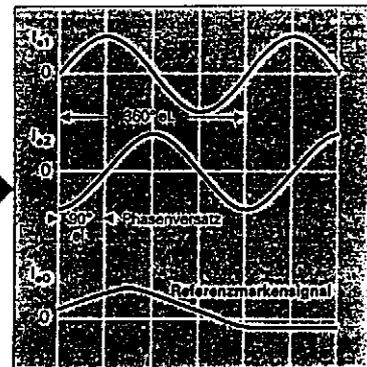
$I_{e1}$ : 7 bis  $16\ \mu\text{A}_{\text{eff}}$

$I_{e2}$ : 7 bis  $16\ \mu\text{A}_{\text{eff}}$

$I_{e0}$ : 2 bis  $8\ \mu\text{A}$  (Nutzanteil)



Photoelektrische Abtastung eines DIADUR-Glasmaßstabs



Abtastsignale

Die HEIDENHAIN-Längenmeßsysteme der Bauform LIDA und LB arbeiten im Auflicht-Verfahren. Sie besitzen Stahlmaßstäbe mit AURODUR-Gitterteilungen aus Goldstrichen mit hohem Reflexionsgrad und matt geätzten Lücken.

Das LIP 101R und das VM 101 benutzen das interferentielle Abtastprinzip mit einem Beugungsgitter-Maßstab. Eine Relativbewegung zwischen Maßstab und Abtastgitter erzeugt unterschiedliche Phasenverschiebungen in den verschiedenen Beugungsordnungen. Durch Überlagerung der Beugungsordnungen (Interferenz) können diese Phasenverschiebungen detektiert und somit der zurückgelegte Weg bestimmt werden. Die Teilungsperiode des Maßstabs beträgt  $8\ \mu\text{m}$ , die Signalperiode  $4\ \mu\text{m}$ . Eine im Abtastkopf integrierte Elektronik liefert zwei sinusförmige Ausgangssignale, die um  $90^\circ$  el. zueinander phasenverschoben sind und die mit den üblichen HEIDENHAIN-Elektroniken (VRZ, EXE) verarbeitet werden können.

Fig. 2) Schematic drawing of the ruler (from Ref. 6)

Technische Kennwerte		LS 704, LS 704C					
Maßverkörperung Teilungsperiode TP Glasart	Glasmaßstab mit DIADUR-Gitterteilung 20 µm G8 ( $\alpha_{\text{therm}} \approx 8 \cdot 10^{-6} \text{ K}^{-1}$ )						
Genauigkeitsklassen	± 5 µm ± 3 µm bis 1240 mm Meßlänge						
Meßlängen ML in mm	170	220	270	320	370	420	
	470	520	—	620	—	720	
	770	820	—	920	—	1020	
	1140	1240	1340	1440	1540	1640	
	1740	1840	2040	2240	2440	2640	
	2840	3040					
Referenzmarken	LS 704	Standard: 1 Referenzmarke in der Mitte der Meßlänge; Sonderausführungen: mehrere Referenzmarken im 50-mm-Raster, ausgehend von der Mitte der Meßlänge, andere Referenzmarken-Lagen auf Anfrage					
	LS 704C	abstandscodiert, mit 1000 · TP					
max. Verfahrensgeschwindigkeit	60 m/min						
Vibration (50 bis 2000 Hz) Schock (11 ms)	≤ 30 m/s <sup>2</sup> ≤ 200 m/s <sup>2</sup>						
erforderliche Vorschubkraft	≤ 10 N						
Schutzarten (DIN 40 050 bzw. IEC 529)	IP 53 bei Einbau nach Montageanleitung IP 64 bei Anschluß von Druckluft						
Betriebstemperatur Lagertemperatur	0 bis 50°C -20 bis 70°C						
Masse	1,0 kg + 2 kg/m Meßlänge						
Lichtquelle	Miniaturlampe 5 V/0,6 W						
Spannungsversorgung	5 V ± 5%/120 mA (ohne Last)						
Ausgangssignale	~ sinusförmig (siehe Seite 2)						
elektrischer Anschluß	Kabel 3 m mit Stecker oder Kabelbaugruppe, Standardkabel­längen 1 m/3 m/6 m/9 m mit und ohne Metall­schutzschlauch zul. Kabellänge zur Folge-Elektronik: 30 m						

Fig. 3) Data sheet of the optical ruler LS 704 (from Ref. 6)

Standard-Typenbezeichnung		T/TS25a102	T/TS50a502	T/TS75a502	T/TS100a502	T/TS150a502		
Elektrische Daten	Elektr. Nutzlänge	25	50	75	100	150	mm	
	Anschlusswiderstand	1	5	5	5	5	kΩ	
	Widerstandstoleranz	20						±%
	Unabhängige Linearität	0,2	0,15	0,1	0,075	0,075	±%	
	Glätte der Ausgangsspannung	0,04	0,02	0,015	0,01	0,01	%	
	Empfohlener Betriebsstrom im Schleiferkreis	< 1						μA
	Auflösung	0,002						mm
	Belastbarkeit bei 40°C	0,6	1,2	1,8	2,5	3,6		W
	Max. Betriebsspannung	25	75	95	110	120		V
	Temperaturkoeffizient des Spannungsteilverhältnisses	< 2						ppm/°C
Isolationswiderstand	100 MΩ bei 500 V = 1 bar							
Durchschlagfestigkeit	500 V <sub>eff</sub> bei 50 Hz 1 min 1 bar							
Mechanische Daten	Mass A	63	88	113	138	188	mm	
	Mechanischer Hub Mass B	31	56	81	106	156	mm	
	Mass C	143	193	243	293	393	mm	
	Gewicht	105	125	145	165	205	g	
	Gewicht der Zugstange mit Kupplung und Schleiferblock	30	40	50	60	80	g	
	Radialspiel der Zugstange	±0,015						mm
	Betätigungskraft (waagrecht)	≤ 0,30 (30)						N (p)
	Beweglichkeit der Kugelpupplung	± 1 mm Parallelversatz ± 5° Winkelversatz						
<b>Betriebsbedingungen</b>		<b>Serienmässiges Zubehör:</b>						
Temperaturbereich	-30...+100°C					4 Befestigungsklammern Z3-31		
Schwingungen	5...2000 Hz A <sub>max</sub> = 0,75 mm A <sub>max</sub> = 20 g							
Stoss	50 g, 11 ms							
Lebensdauer	> 100 · 10 <sup>6</sup> Überläufe bei ≤ 2,5 m/s und ≤ 1 μA Schleiferstrom							
Belastbarkeit	siehe Tabelle von diesem Wert fallend auf 0 W bei 110°C							
<b>Empfohlene Beschaltung</b>								
<b>Wichtig:</b>								
Sollen die im Datenblatt angegebenen Werte wie Linearität, Lebensdauer, Mikrolinearität, Erschütterungsfestigkeit, TK des Spannungsteilverhältnisses eingehalten werden, so ist eine belastungslose Abnahme der Schleiferspannung mit einem als Spannungsfolger geschalteten Operationsverstärker erforderlich. (I <sub>0</sub> ≤ 1 μA)								

Fig. 4) Data sheet of the linear potentiometer LINOPOT (Fa. NOVOTECHNIK)

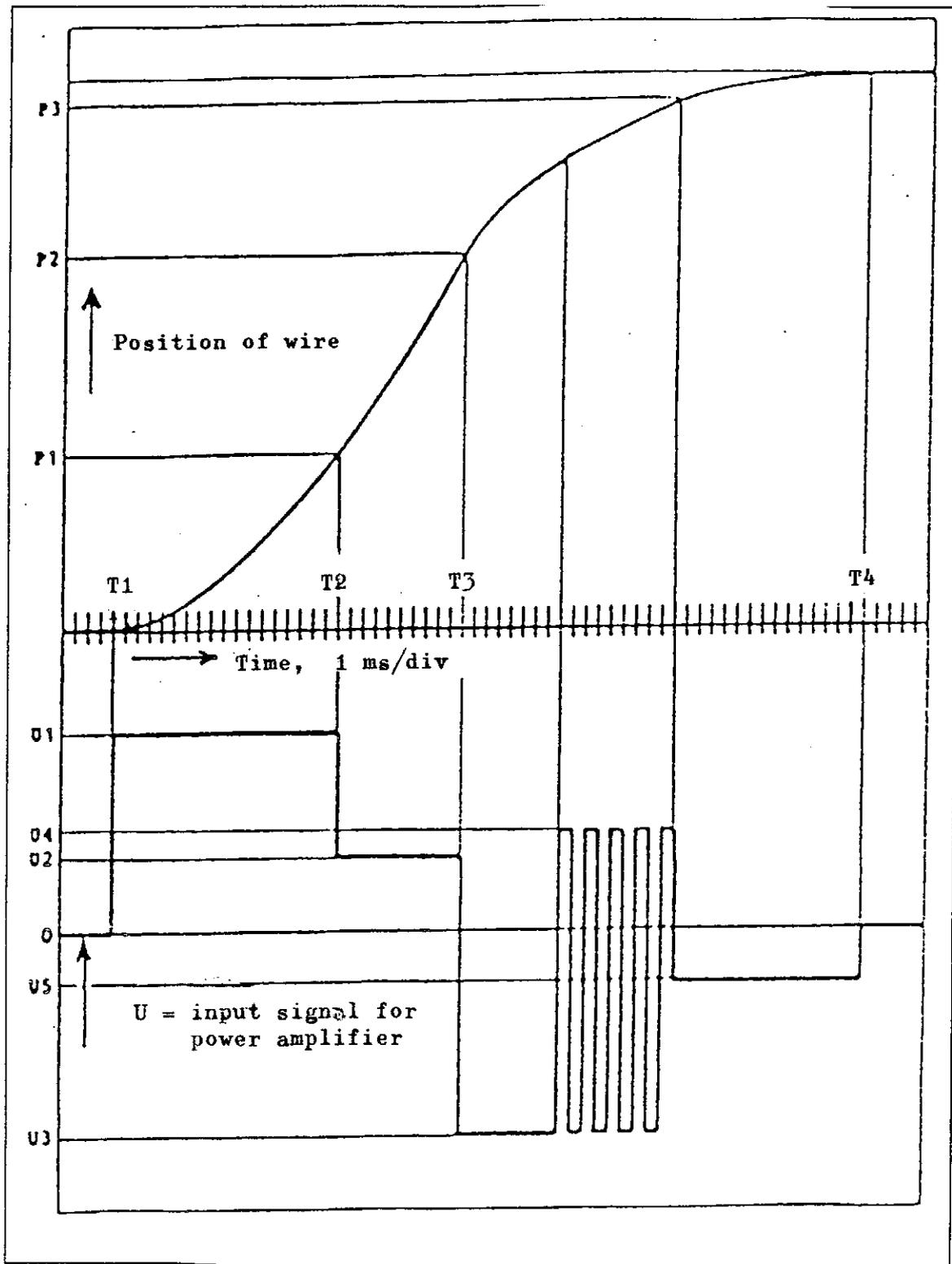


Fig 5) Position and DAC output during the displacement of the PS wire scanner (Ref. 5). U is the (programmed) driving voltage for the DC motor. Between T1 and T2 the wire is accelerated, between T2 and T3 the speed is nearly constant. In this range the wire crosses the beam. At T3 the speed begins to slow down and the movement stops at T4.