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A SOLUTION TO THE INCREASING ELECTROSTATIC SEPTUM THICKNESS PROBLEM

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Distribution

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1. Introduction

A comparison of the beam losses with the extracted intensities during a fixed target run, period 2B, 1982, has shown that the effective thickness of the first e.s. septum unit increases during operation$^{1)}$. For a high intensity slow extraction at 1.4 10^{13} ppp this increase is as much as 100% or 0.15 mm.

It was then proposed $^{1)}$ to realign the first septum once the effective thickness has stabilised after a few hours of operation. Beam loss readings then will allow to conclude whether the septum is wharped, if no improvement can be obtained, or whether the septum remains straight but is only misaligned. The MCR conducted tests have shown that the septa become wharped.

Several hypotheses on the cause have been launched unsuccesfully like uneven heating of the anode suspension or friction between septum wires and the anode. It is shown in this report that a transversal thermal gradient in the anode causes the septum to bend in the horizontal plane.

A solution would be to make the first anode in each extraction channel of Invar instead of stainless steel.

2. The thermal gradient in the anode

There are two sources of heat which cause a transversal thermal gradient in the anode:

- The heat developed at the centre of the septum wires, is conducted to the tips of the anode setting up a very small thermal gradient. For the first septum the energy dissipation is roughly 0.2 W/10^{13} ppp.

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1) Observation of an increase of the effective thickness of the e.s. septa, R.L. Keizer, SPS/ABT/Techn.Note/82-4.

- The secondary particles are ejected mainly in forward direction. The intensity diminishes with increasing scattering angle. The anode tips being nearest to the secondary beam axis are therefore heated faster. The dissipated energy in the first anode is estimated to be of the order of 20 W/10^{13} ppp.

The transversal thermal gradient causes the anode to bend in the horizontal plane with the radius of curvature directed to the centre of the SPS. The sagitta f of the septum is then given by

$$f = \frac{\alpha \ell^2 \Delta T}{8 w} \qquad (1)$$

For an anode, with a coefficient of thermal expansion $\alpha = 1.2\ 10^{-6}/°C$, length ℓ = 3000 mm and width w = 230 mm, a doubling of the septum thickness, f = 0.15 mm, is expected to occur with a temperature difference across the anode ΔT of 2.6°, or

$$\frac{f}{\Delta T} = 0.059 \text{ mm/°C} \qquad (2)$$

3. The anode temperature measurement

The temperature increase of the anode has been measured with the ZST station installed in LSS2 between the ZS2 and ZS3 e.s. septa. The measurements were done with platinum thermistors mounted on the outside of the anode. A typical result is shown in Fig. 1.

The curves are characterized by small dips of approximately 1°C produced when the extraction is interrupted for a few pulses. This effect is due to the high Z-value of Pt which heats 8x faster than stainless steel in a nuclear radiation field. When the beam is stopped, thermal equilibrium is reached virtually immediately. True temperatures are therefore measured only when be beam is off.

The thermal time constant is 1.2 - 1.5 h. The temperature increase is in the order of 3°C/10^{13} ppp.

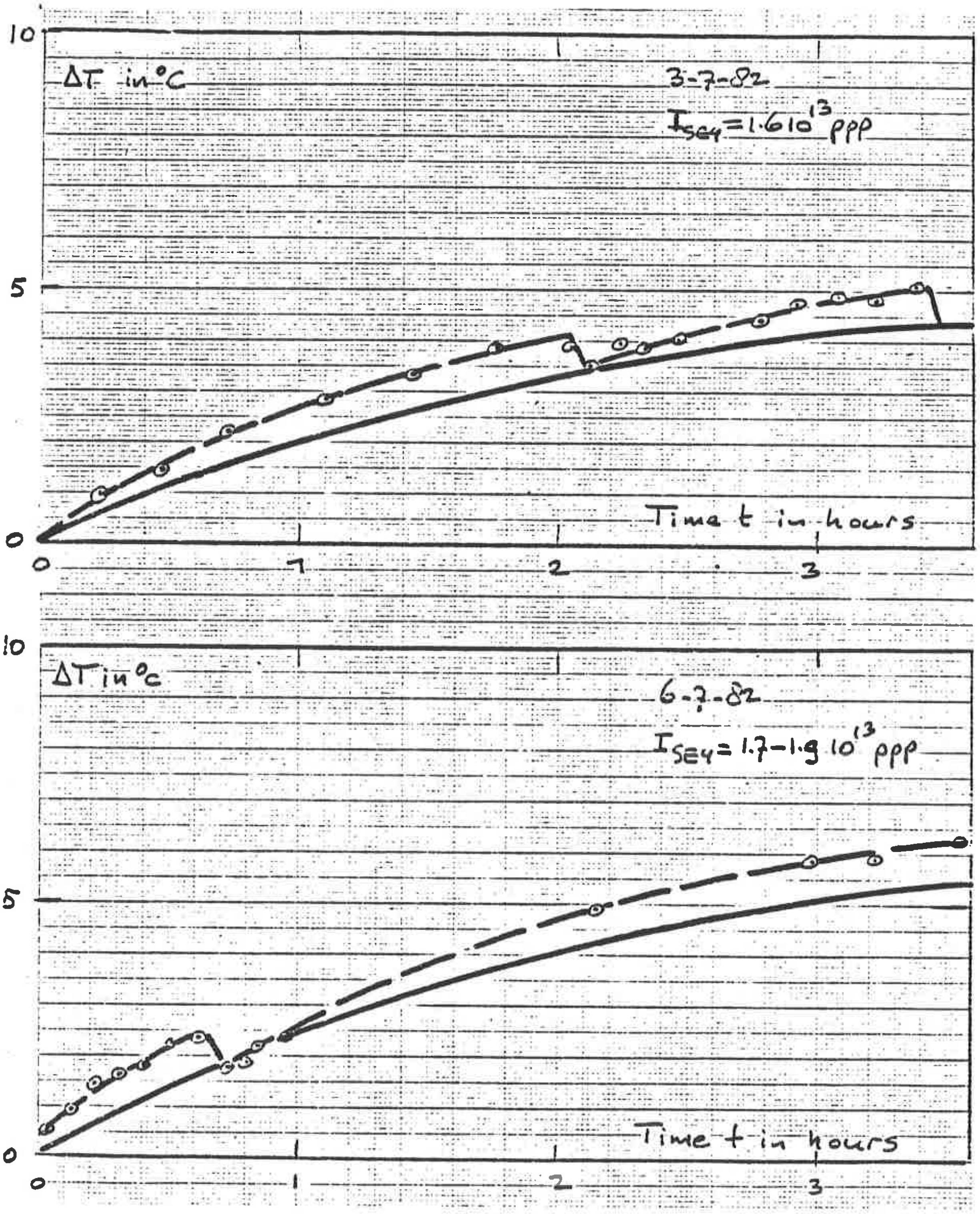

Fig. 1 - Temperatures of the ZST-anode, Slow Extraction in LSS2

At $t = 0$ the value of $\frac{dT}{dt} = 1.5$ °C/h/10^{13}ppp

The thermal capacity of the anode is approximately $8.3\ 10^4$ J/°C. The heating power W of the p-beam in ZS2 and ZS3 is therefore

$$W = C\frac{dT}{dt} = 34 \quad W/10^{13}\text{ppp} \qquad (3)$$

The energy dissipation in the first anode may be estimated by assuming that the beam loss monitor readings are representative for the local losses only. Table 1 gives the beam loss distribution, in %, and the measured and calculated power losses in the ZS'. The first septum therefore would receive 23 W/10^{13} ppp of secondaries power.

The total energy loss in the entire extraction system (anodes only) therefore would amount to 127 W/10^{13} ppp.

	ZS1	ZS2	ZS3	ZS4	ZS5
Beam loss signal strength, % of total	18	27	27	17	11
Measured energy distribution, W	-	34	34	-	-
Calculated energy distribution, W	23	34	34	22	14

Table 1 – The energy distribution along the LSS2 extraction channel

Another way of evaluating the power dissipation would be to assume that for line targets the angular distribution of the energy deposited by secondaries is given by an exponential law²⁾.

$$\frac{dW(\theta)}{d\theta} = W_0 e^{-b\,\theta} \qquad (4)$$

Furthermore, it is assumed that the energy received by each septum is determined by the angular interval subtended by the inside of the anode. Therefore the energy absorbed by a particular septum W(ZSi) follows from

$$W\,(ZSi) = W_0 \int_{min}^{max} e^{-b\,\theta}\, d\theta \qquad (5)$$

The energy W_0 is taken as the energy received by all septa

$$W_0 = \sum_{1}^{5} W(ZSi) \qquad (6)$$

Such a calculation is shown in Fig. 2. The predicted percentages for ZS2, ZS3 and ZS4, knowing that the three units receive 71% of the total energy W, see Table 1, is well predicted by the expression

$$\frac{dW(\theta)}{d\theta} = W_0 e^{-0.55\,\theta} \qquad (7)$$

where θ is given in mrad.

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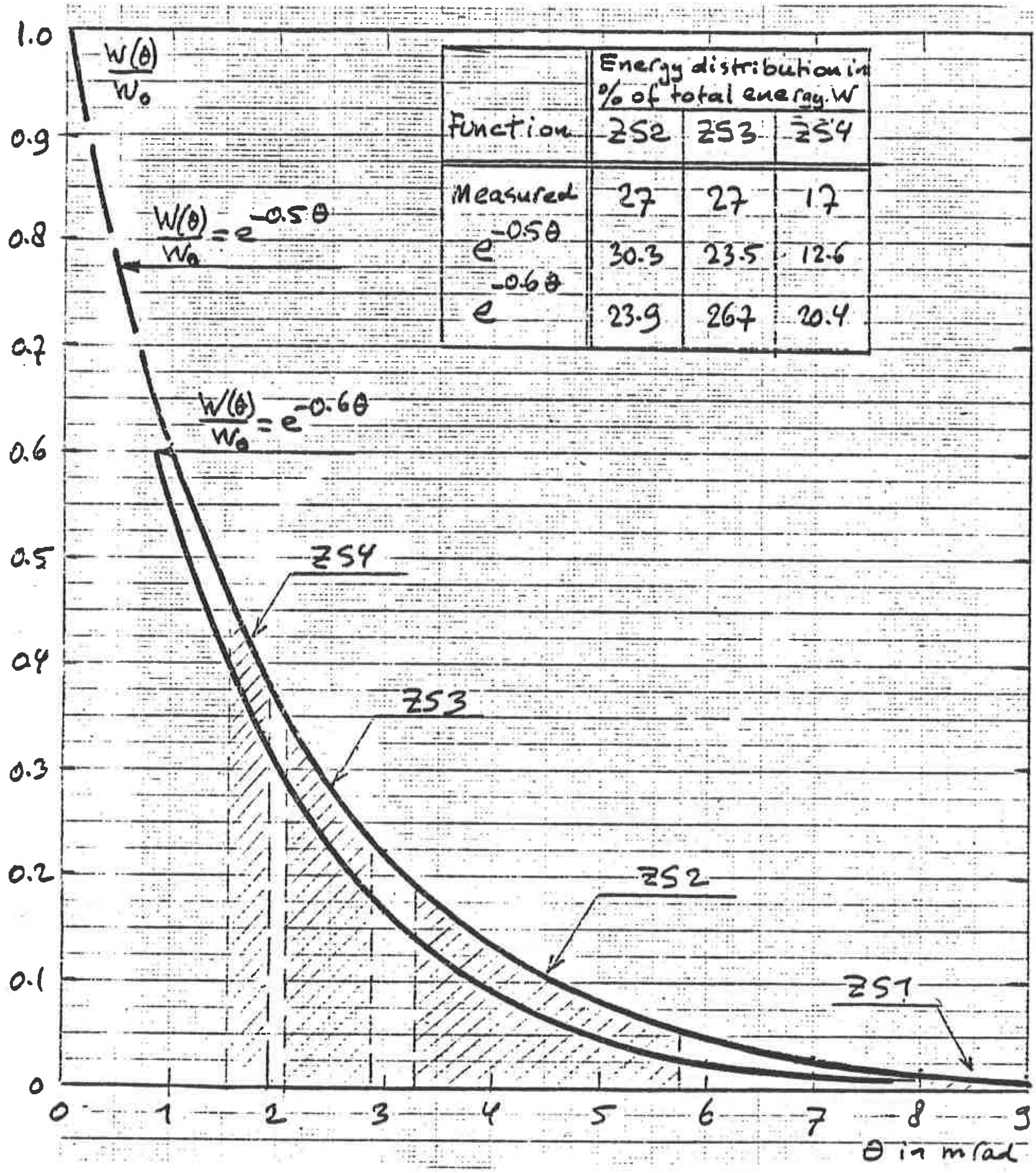
2) Estimation of the booster beam losses. F. Hoyer, K. Goebel and F. Schindl, 2nd draft 21.4.69.



Function	Energy distribution in % of total energy W		
	ZS2	ZS3	ZS4
Measured	27	27	17
$e^{-0.5\theta}$	30.3	23.5	12.6
$e^{-0.6\theta}$	23.9	26.7	20.4

Fig. 2 - The Angular Secondaries Energy Distribution emerging from the ZS1 Septum in LSS2

4. The measured thermal deformation of the anode

An existing anode body, without septum-wires, has been placed on a flat table with supports placed near the up- and downstream ends as shown in Fig. 3. Energy was supplied to the anode tips by a heating tape powered by a Variac. The thermal gradient was measured by thermistors as shown. The deformation of the anode in the horizontal and the vertical plane was monitored with dial gauges.

No vertical deformation was observed, but as Fig. 4 shows, the deflection in the horizontal plane is very neatly predicted by the theoretical formula (1). Measurable deflections are produced by energy fluxes as small as 5 W.

With an energy input of the correct order, approximately 20 W representing the loss of 10^{13} ppp, a deformation of 0.08 mm was measured after approximately 1 hour. This corresponds well with the observed values for the increase of the effective septum thickness.

The thermal gradient was created with practically no temperature increase of the rear side of the anode, as measured with Th3.

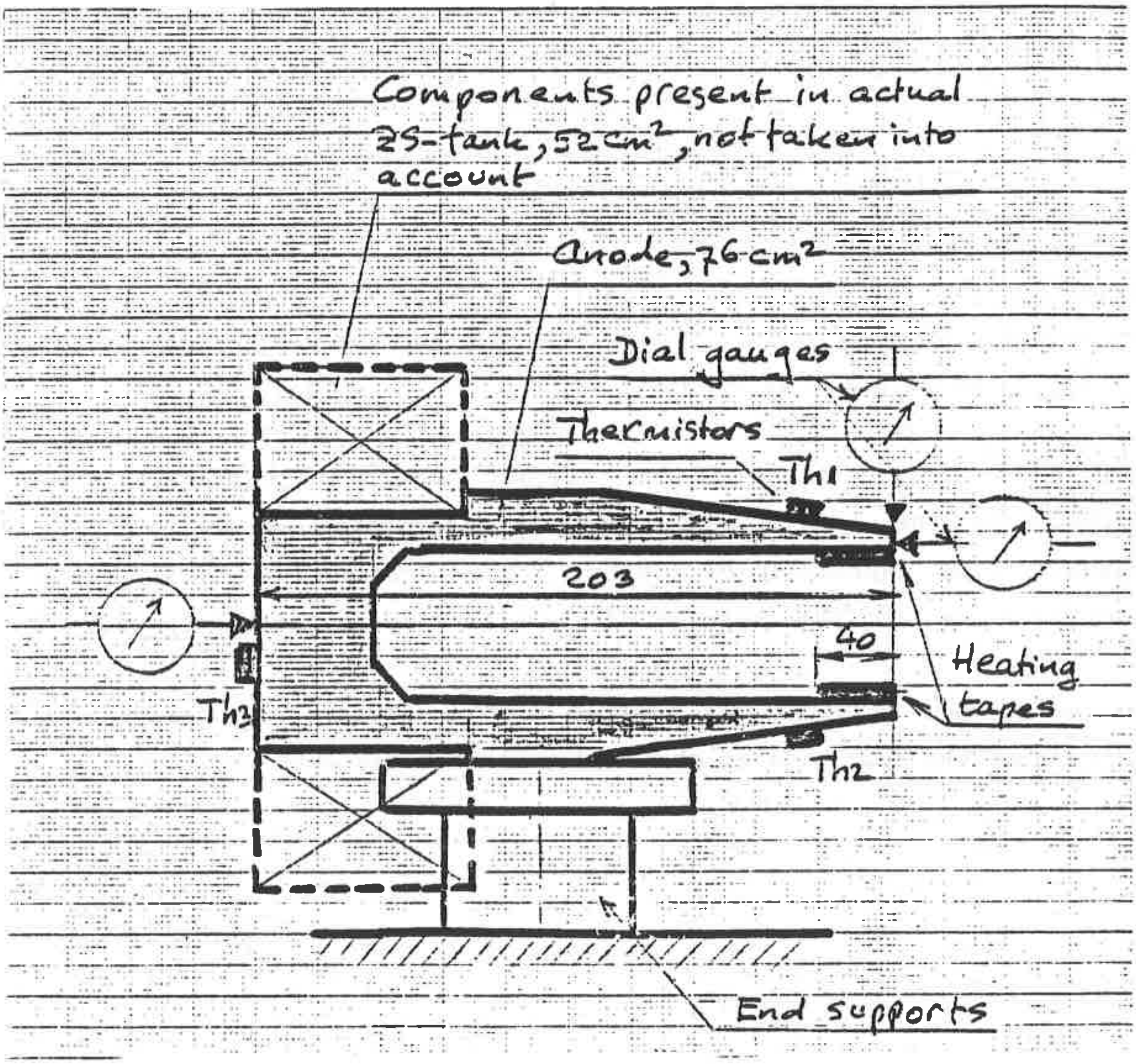


Fig. 3 -Measurement of the Thermal Deformation of the Anode

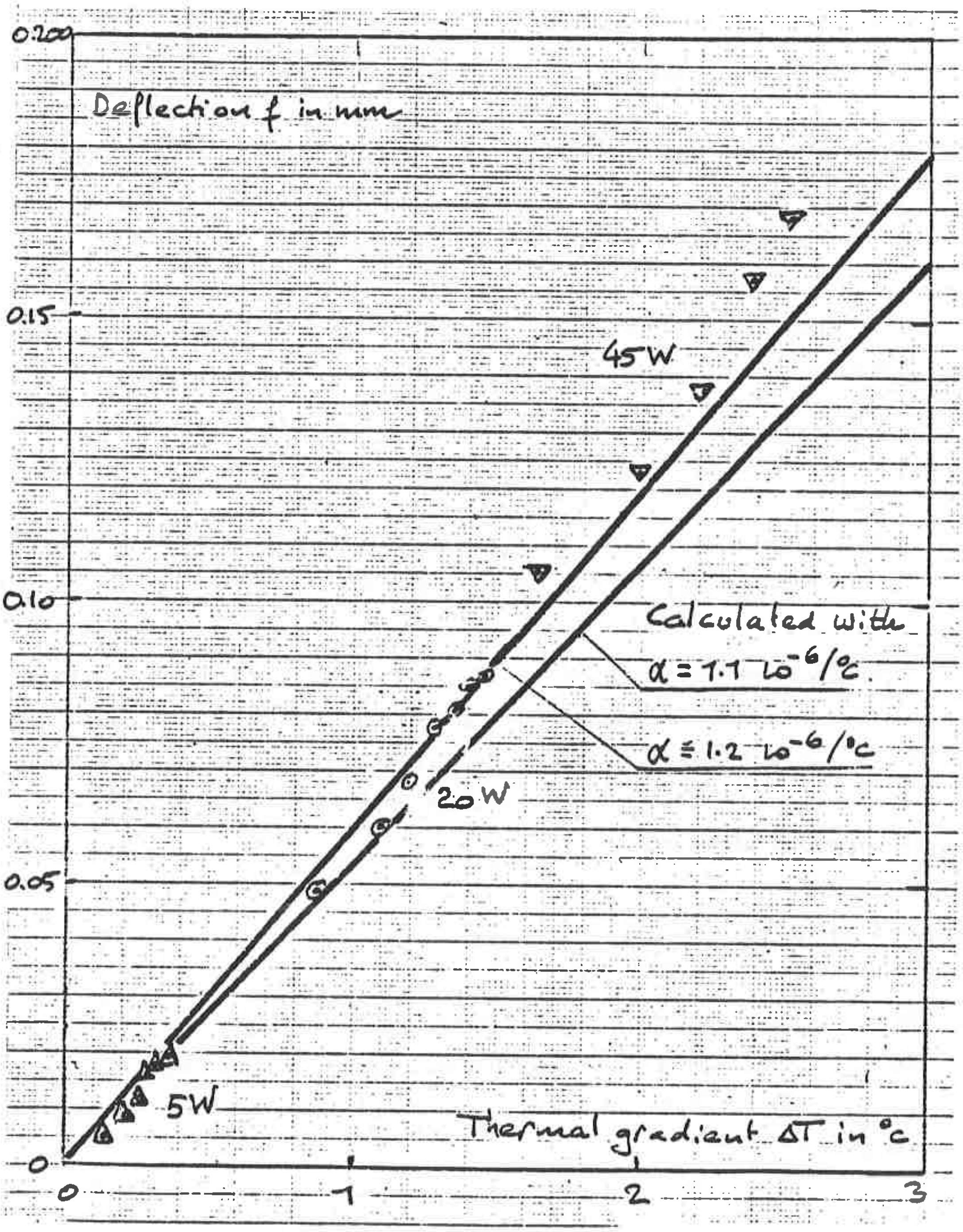


Fig. 4 - Deformation of the Anode as a Function of the Thermal Gradient

5. Conclusion

It has been shown that:

1) The main source of thermal energy is provided by the secondaries produced in the septum wires. Heating by conduction through the wires may be neglected.

2) The angular distribution of the energy deposited by the secondaries follows the exponential law

$$\frac{dW(\theta)}{d\theta} = e^{-2.55\,\theta}$$

which proves that the anode tips heat much faster than the more remote parts of the anode body.

3) The measured deformation of ZS1, equal to 0.15 mm (period 2B, LSS2) will be produced by an energy flux of some 30 W creating a thermal gradient of 2.6°C across the anode. These effects are perfectly calculable and have been verified by laboratory experiments.

6. Proposed solution

- Replace the existing anode body by a similar item made of Invar. The coefficient of thermal expansion of this material is virtually zero between 0 and 50°C and remains low up to 100°C.

- In this case it would be useful to use 0.05 instead of 0.10 mm diameter wires for the entire anode. The 2000 wires then represent exactly one scattering length for p-nucleus interaction. The primary proton beam at the downstream end of the septum will then be reduced to 37% of its upstream value.

- The anode should possibly be enlarged to provide for more intense future beams.

- The anode assembly may have to be redesigned to cope with problems proper to machining and stabilizing Invar and to reduce manufacturing costs.

7. Acknowledgments

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