

MAGNETIC MEASUREMENTS ON THE BENDING MAGNETS  
OF THE BEAM TRANSPORT SYSTEM OF THE CERN P.S.

1. GENERAL DESCRIPTION.

For the deflection of charged particle beams from the CERN P.S. a number of bending magnets have been constructed. Their pole faces are plane and rectangular. Most of the magnets have straight poles. To obtain a somewhat higher flux density over a narrower width some of the magnets have tapered poles. A cross-section of the magnets is shown in Fig. 1. The axial length of the poles is 1 metre for some of the magnets and 2 metres for the remaining ones. In terms of pole profile and length there are thus four different types. The nominal distance between the pole faces is 0.14 metre. It can be changed, however, to 0.11 m, 0.17 m or 0.20 m, by changing the spacing plates indicated by the dimension H in Fig. 1. The coils have hollow water cooled conductors. The nominal resistance is 0.2 ohm for all magnets.

The magnets are mounted on concrete supporting blocks. The blocks which also may act as radiation shielding are fitted with special devices for fine adjustment of position and orientation of the magnets.

The main parameters are collected in Table 1.

2. METHODS OF MEASUREMENT.

2.1. Definitions and symbols.

The coordinate system used is indicated in Fig. 1. Some definitions and symbols are given below.

$B_{z0}$  = Flux density in z-direction at the point (0,0,0)

$I_M$  = Magnet excitation current

$L_{eq} = \frac{1}{B_{z0}} \int_{-\infty}^{+\infty} B_z(y) dy = \text{Equivalent length}$

$P = \int_{-\infty}^{+\infty} B_z(y) dy = \text{Bending power}$

### 2.2. The magnetisation curve.

The magnetisation curve  $B_{z0}(I_M)$  was measured by means of the Hall effect. The circuit used is indicated schematically in Fig. 2. The Hall voltage and the Hall current were both measured by means of a compensator.

### 2.3. Distribution of the flux density.

The transverse distribution (in x - direction) of

$$\frac{B_{z,x} - B_{z,0}}{B_{z,0}} = \frac{\Delta B}{B}$$

was measured by means of the Hall effect. The signal from a moveable Hall plate was opposed to the signal from a fixed reference Hall plate. The difference signal from the two matched Hall plates was measured with a millivolt-meter of high internal resistance, when necessary after some electronic amplification. By this difference method the influence of fluctuations in magnet current is practically eliminated.

### 2.4. Bending power and equivalent length.

The bending power

$$P = \int_{-\infty}^{+\infty} B_z(y) dy$$

was first determined well below saturation (at  $0.64 \text{ Wb/m}^2$ ) by means of graphical integration of Hall effect point measurements. The same quantity was then measured by means of a long narrow coil and an electronic integrator. The length of the coil was 4 m and its width 20 mm. The effective area was of the order of  $1 \text{ m}^2$ .

These two measurements provide a direct conversion constant

$$K = \frac{\int_{-\infty}^{+\infty} B_z(y) dy}{V_i}$$

for conversion from integrator voltage  $V_i$  to magnetic bending power. The bending power as a function of current was then measured with the long coil and the integrator.

The transverse distribution was determined by transverse displacement of the coil between the position  $x = a$  and  $x = 0$ .

The integrator output voltage is then directly proportional to the difference in bending power at  $x = a$  and  $x = 0$ . In this way the effect of drift in the measuring apparatus and the magnet current is reduced to a minimum.

The equivalent length

$$L_{eq} = \frac{1}{B_{z,0}} \int_{-\infty}^{+\infty} B_z(y) dy$$

is obtained by simple calculation of the ratio between bending power and flux density.

#### 2.5. Correction for saturation and edge effect.

A uniform distribution of  $B$  and  $P$  over a rectangular area was aimed at. This was approached by mounting shims on the pole faces (Fig. 1) and end pieces on the ends of the poles. The distribution of  $B$  and  $P$  was measured at various values of flux density for different combinations of shims and end pieces.

From the resulting curves it should be easy to select the most suitable shim to achieve an optimum of the distribution of  $B$  and  $P$  for any given value of  $P$ .

### 3. RESULTS AND CONCLUSION.

The flux density and bending power as a function of magnet current are given in Fig. 3 and Fig. 4 for all four magnet types. The transverse distributions of the same quantities are given in Fig. 5 - Fig. 16. The best distribution of  $B$  for magnets fitted with standard ( $7 \times 30 \text{ mm}^2$ ) shims (see Fig. 1) occurs at about  $1.1 \text{ Wb/m}^2$  for the magnets with straight poles and at about  $1.4 \text{ Wb/m}^2$  for magnets with tapered poles. The optimum distribution of  $P$  at the same values of  $B$  are obtained by fitting end pieces of dimensions  $(12 \times 130 + 12 \times 80) \text{ mm}^2$  and  $20 \times 130 \text{ mm}^2$  for the straight and tapered pole profiles respectively (see Fig. 1). With standard shims but no end pieces the optimum distributions of  $P$  occur at  $0.5 \text{ Wb/m}^2$  and  $1.0 \text{ Wb/m}^2$  respectively.

A comparison of the characteristics Fig. 5 - Fig. 16 indicates a close resemblance between the transverse distributions of both B and P for the 1 metre and the 2 metre magnets of same pole profile. More detailed characteristics are therefore given only for the 1 metre magnets. Fig. 17 - Fig. 30 show the effect of different shim thickness on the distribution of flux density and bending power for the two different types of 1 metre magnets.

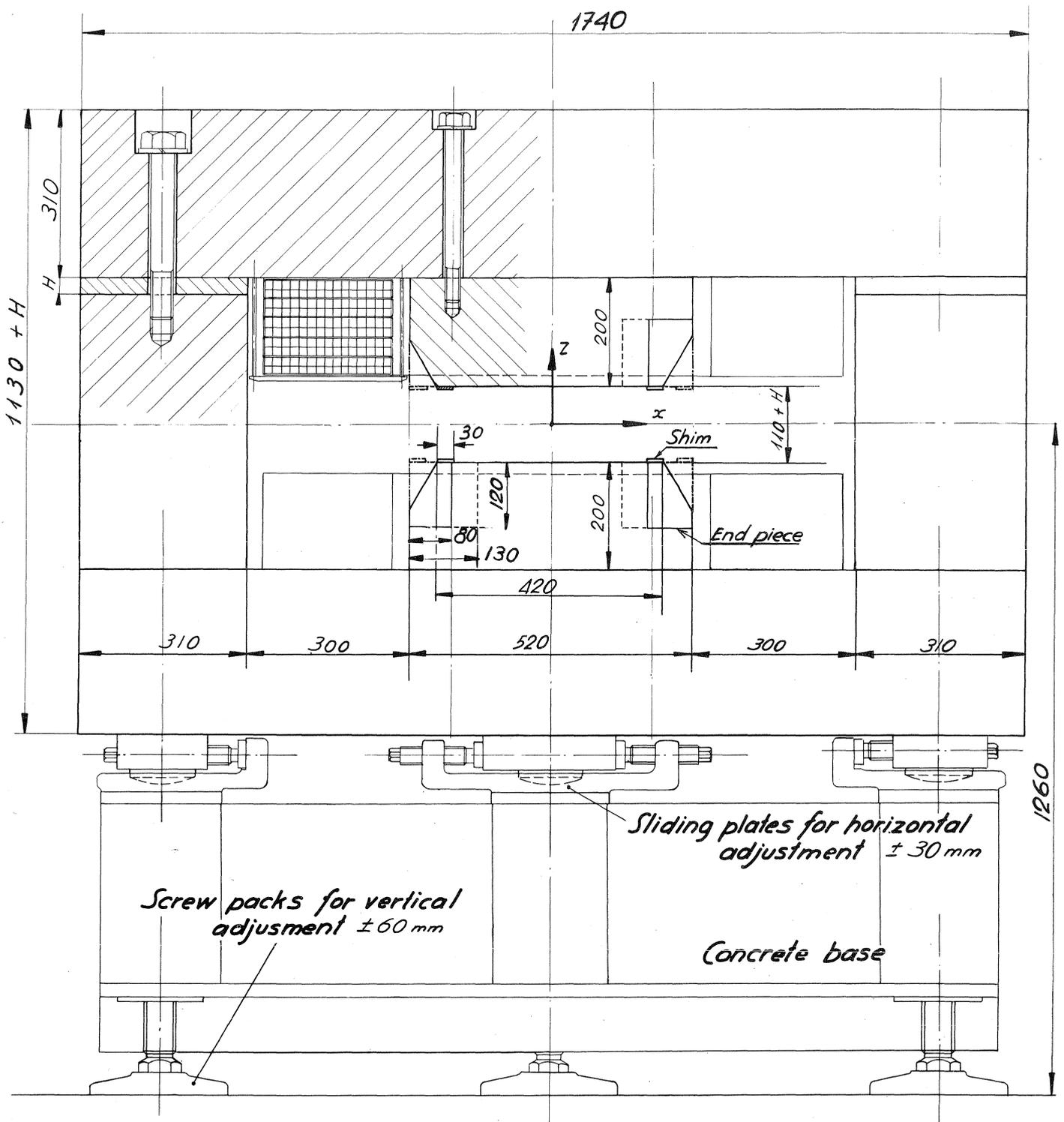
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G. Pluym  
B. de Raad

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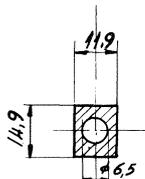
Distribution : (open)  
FBC Group  
Parameter Committee

T A B L E 1

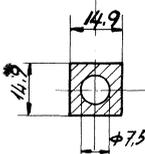
Type	1 metre Bending Magnet Straight Poles	2 metre Bending Magnet Straight Poles	1 metre Bending Magnet Tapered Poles	2 metre Bending Magnet Tapered Poles
Pole face	1 m x 0.52 m	2 m x 0.52 m	1 m x 0.42 m	2 m x 0.42 m
Gap height	for all types 0.11 , <u>0.14 nominal</u> , 0.17 and 0.20 m			
Nominal Current $I_N$	675 A	830 A	675 A	830 A
Bending power at $I_N$	1.88 Wb/m	3.63 Wb/m	1.96 Wb/m	3.80 Wb/m
Flux density at $I_N$	1.64 Wb/m <sup>2</sup>	1.74 Wb/m <sup>2</sup>	1.74 Wb/m <sup>2</sup>	1.84 Wb/m <sup>2</sup>
Resistance at 20°C	for all types 0.195 ohm			
Max. temp.	for all types 40° C at inlet and 80° C at outlet			
Weight of magnet and base	15 + 3 ton	30 + 6 ton	15 + 3 ton	30 + 6 ton



$H = 0 ; 30\text{mm (nominal)} ; 60\text{mm or } 90\text{mm.}$   
*Adjustable by spacing plates*



*Conductor for 1 meter magnet*  
*180 turns per pole*



*Conductor for 2 meter magnet*  
*150 turns per pole*

*Fig. 1 Cross-section of bending magnets*

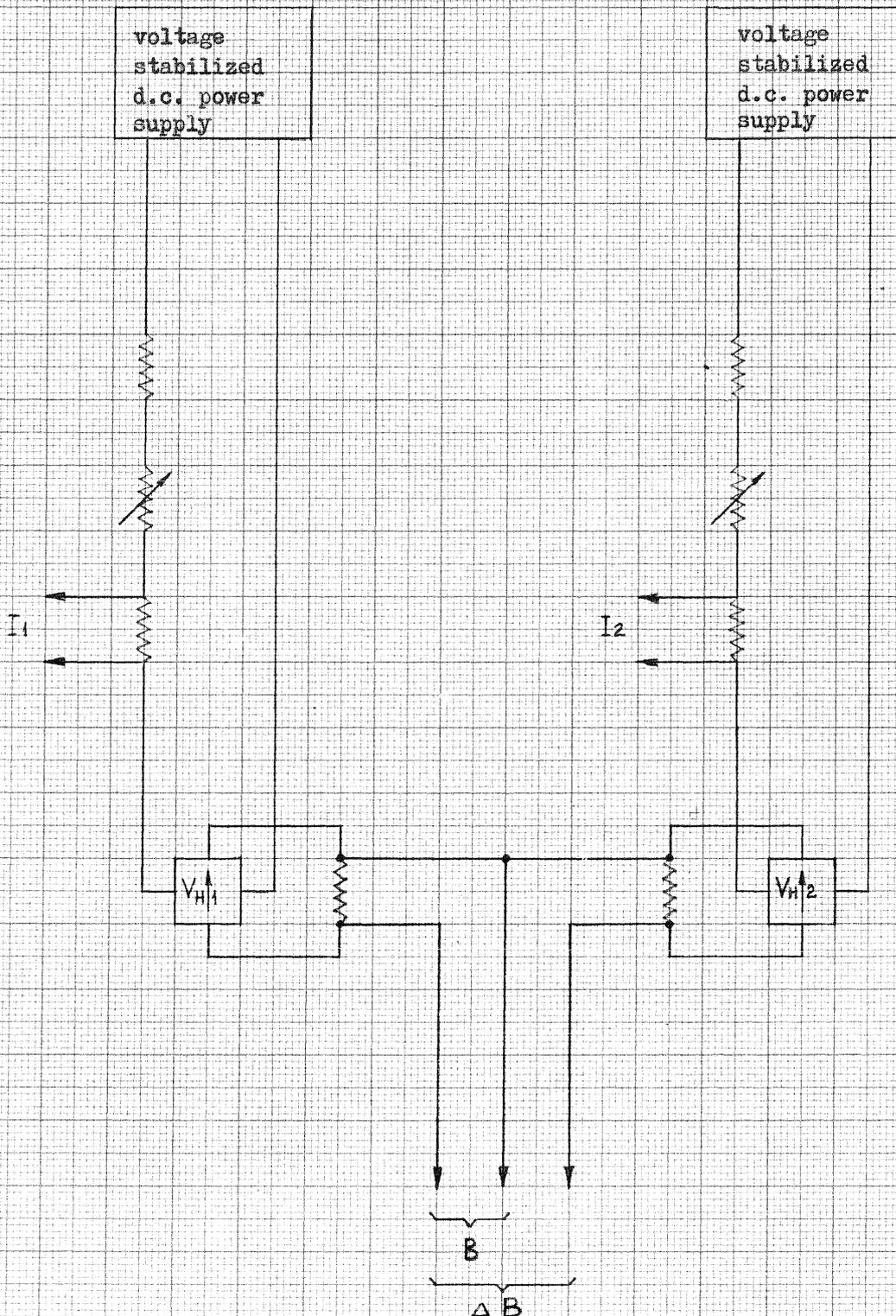
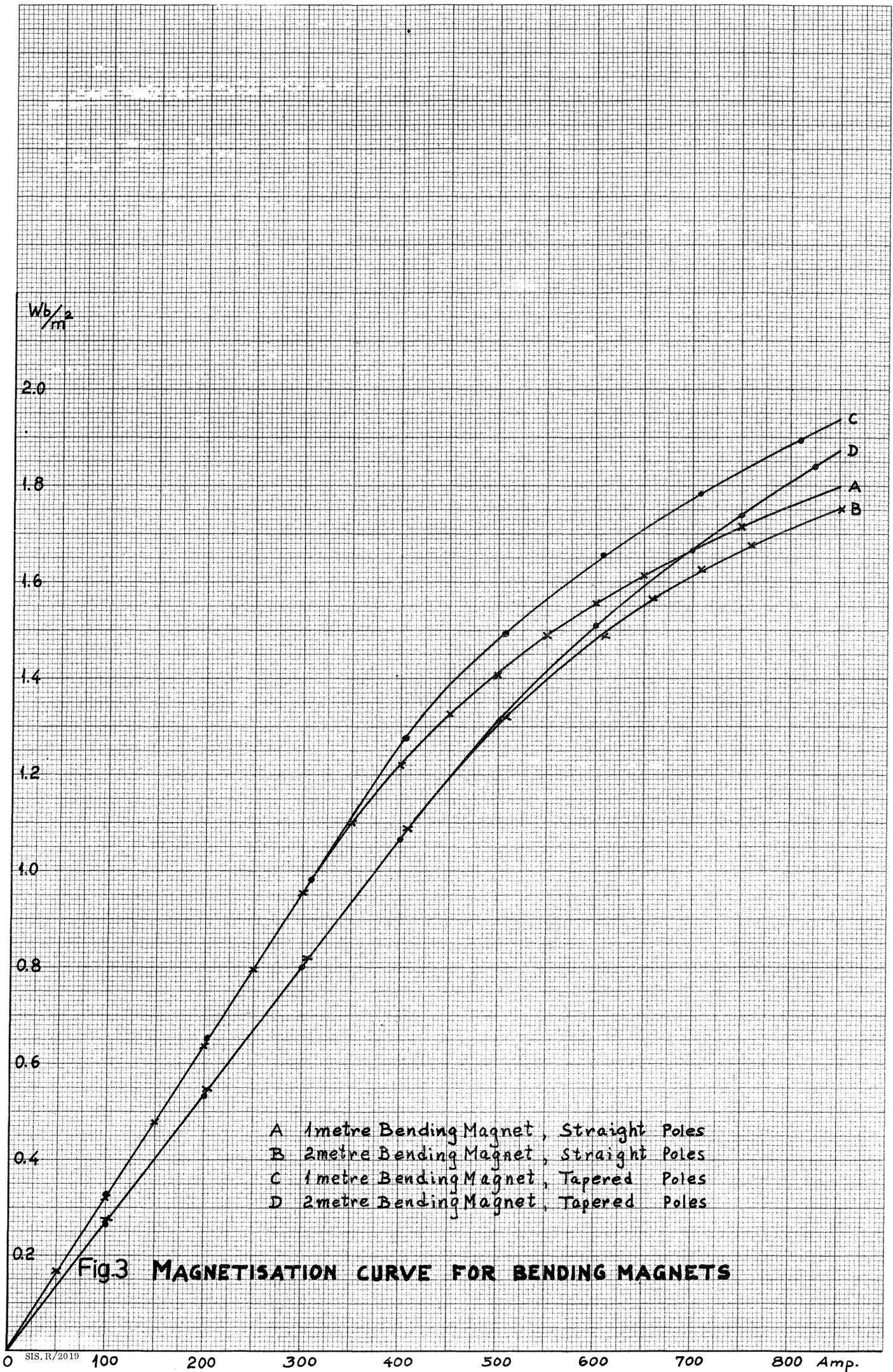


Fig.2 Hall Generator Circuit for Magnetic Field Measurements

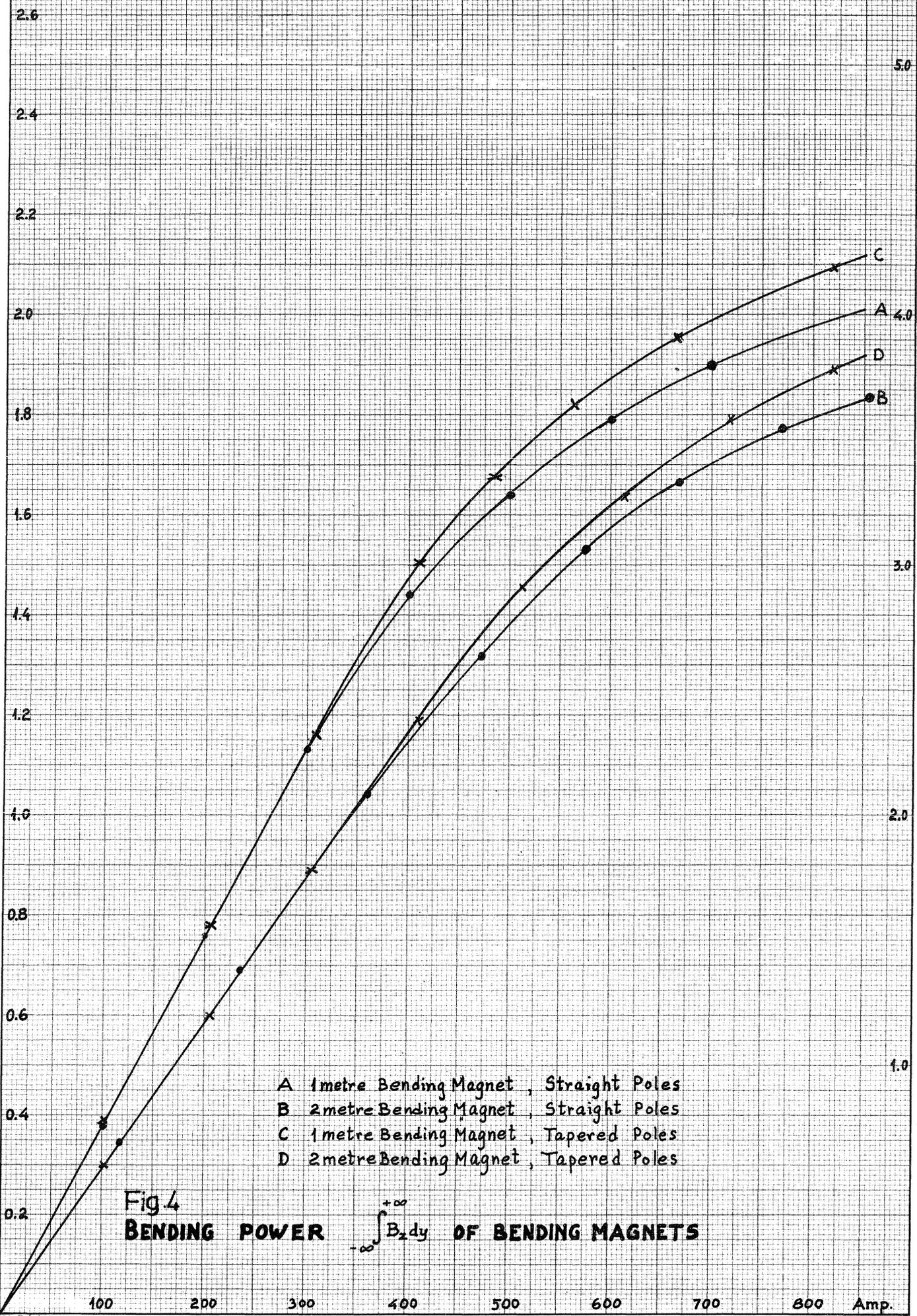


A 1metre Bending Magnet, Straight Poles  
 B 2metre Bending Magnet, Straight Poles  
 C 1metre Bending Magnet, Tapered Poles  
 D 2metre Bending Magnet, Tapered Poles

**Fig.3 MAGNETISATION CURVE FOR BENDING MAGNETS**

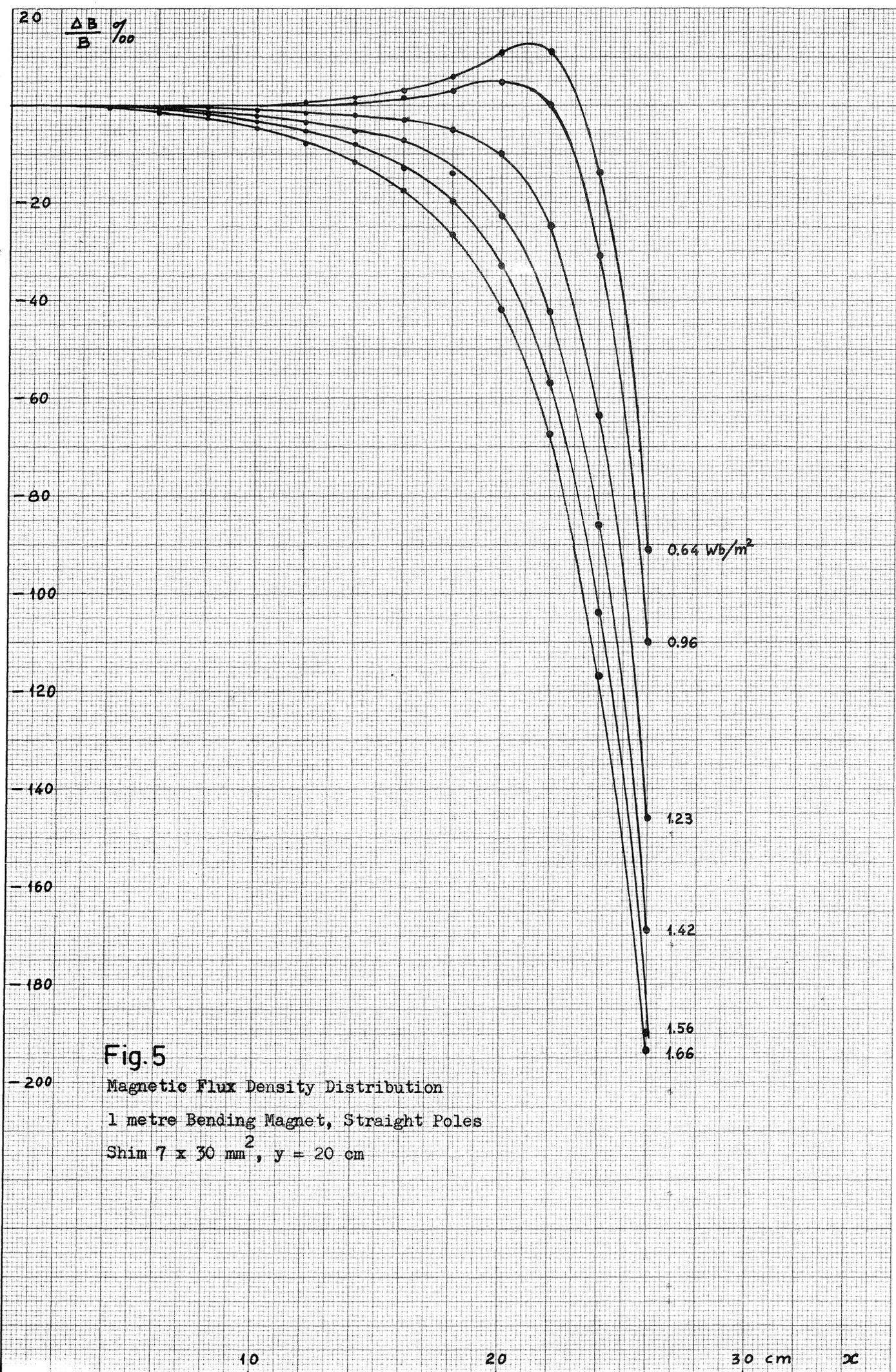
Curve A and C  
Wb/m

Curve B and D  
Wb/m

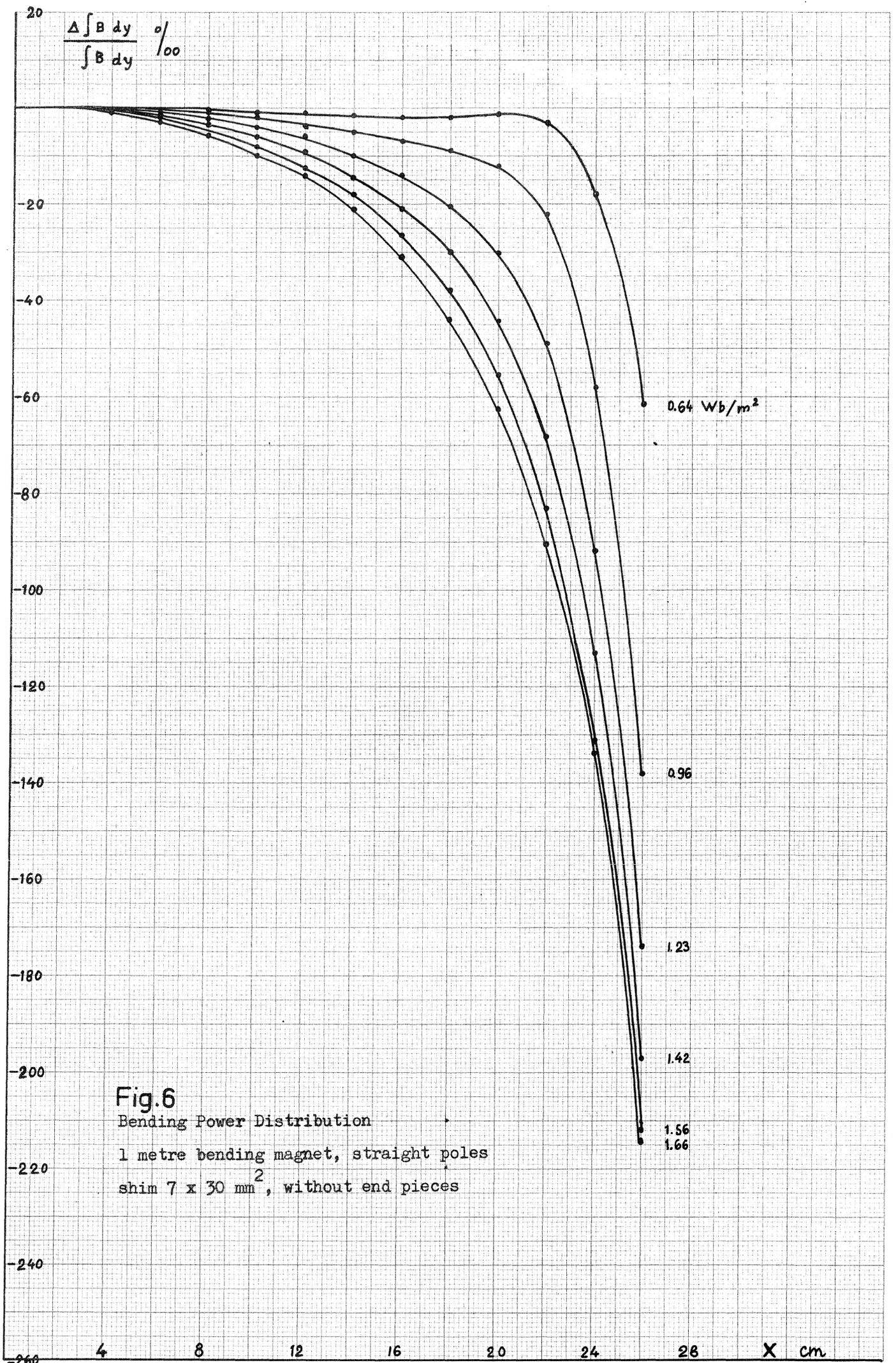


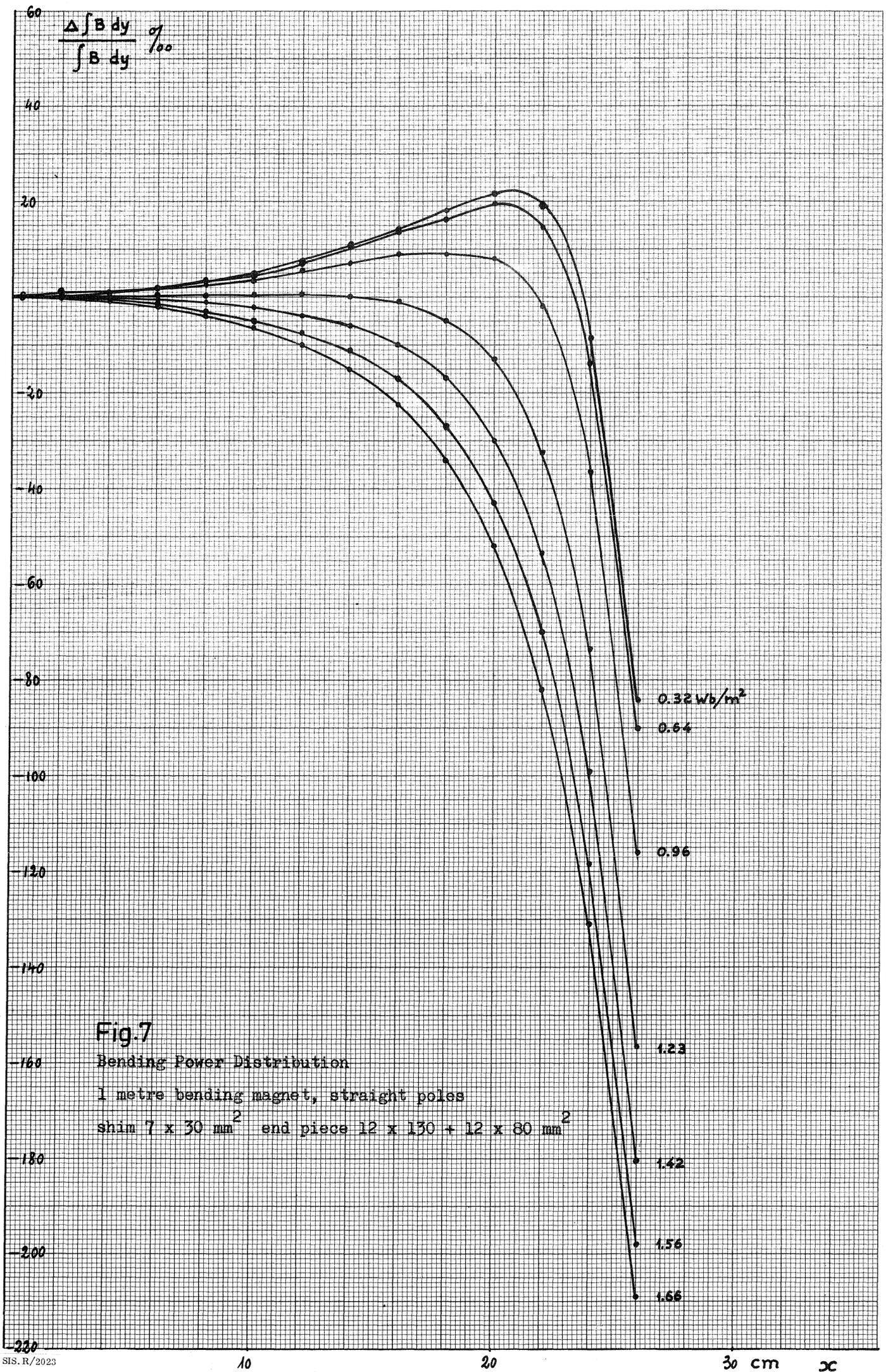
- A 1 metre Bending Magnet , Straight Poles
- B 2 metre Bending Magnet , Straight Poles
- C 1 metre Bending Magnet , Tapered Poles
- D 2 metre Bending Magnet , Tapered Poles

Fig. 4  
BENDING POWER  $\int_{-\infty}^{+\infty} B_z dy$  OF BENDING MAGNETS



**Fig. 5**  
 Magnetic Flux Density Distribution  
 1 metre Bending Magnet, Straight Poles  
 Shim 7 x 30 mm<sup>2</sup>, y = 20 cm



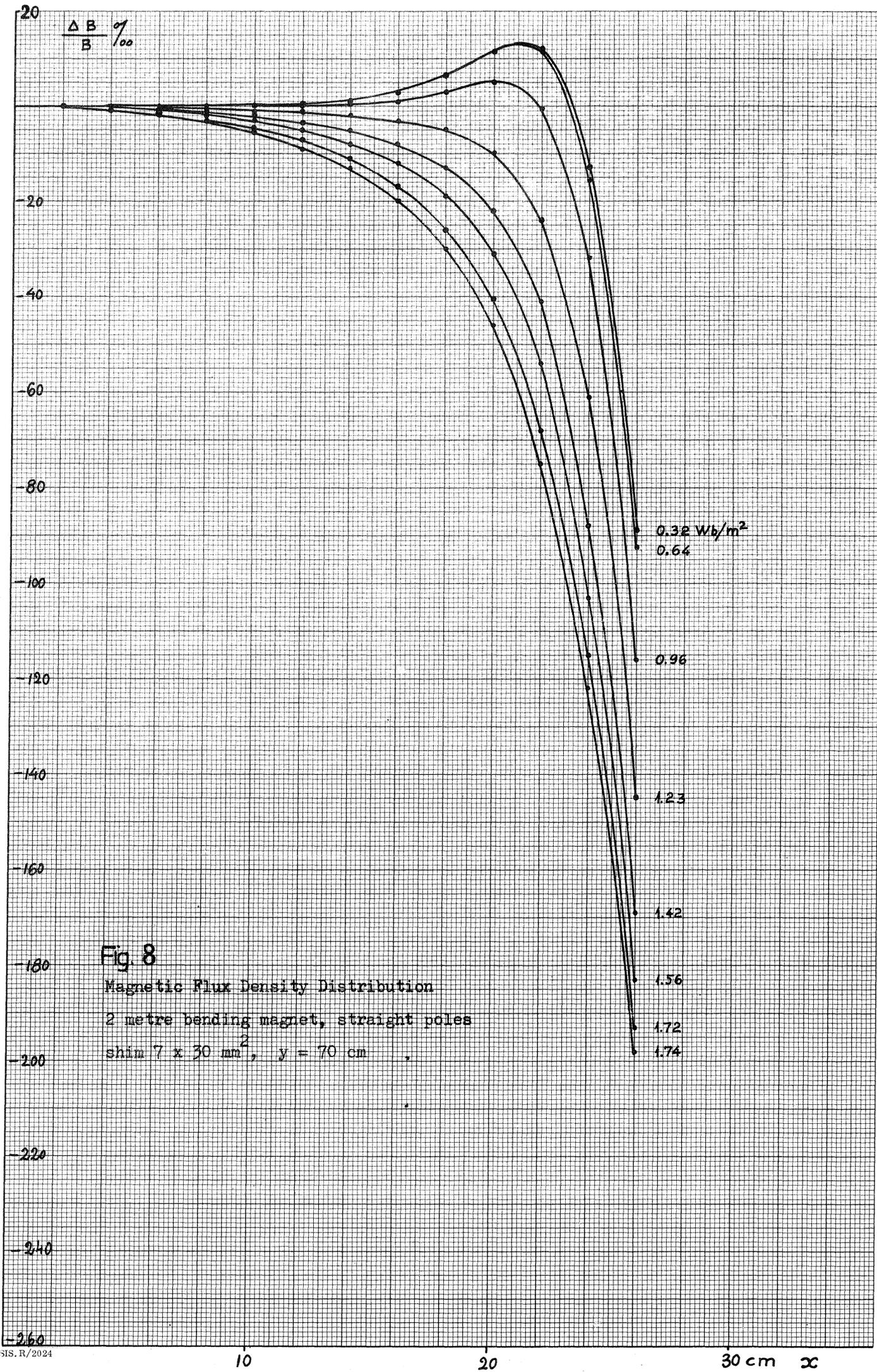


**Fig.7**

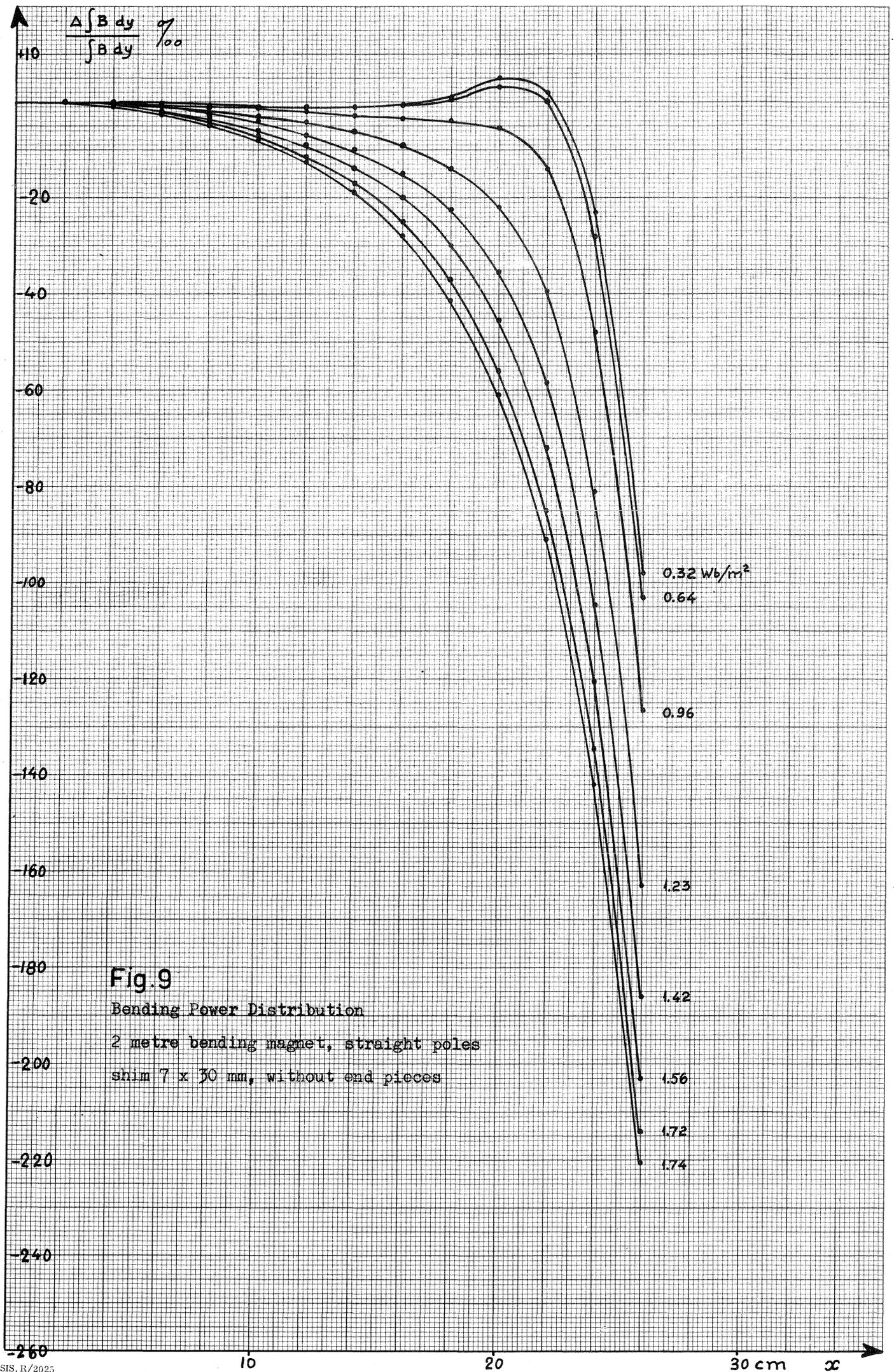
Bending Power Distribution

1 metre bending magnet, straight poles

shim 7 x 30 mm<sup>2</sup> end piece 12 x 130 + 12 x 80 mm<sup>2</sup>



**Fig. 8**  
 Magnetic Flux Density Distribution  
 2 metre bending magnet, straight poles  
 shim 7 x 30 mm<sup>2</sup>, y = 70 cm

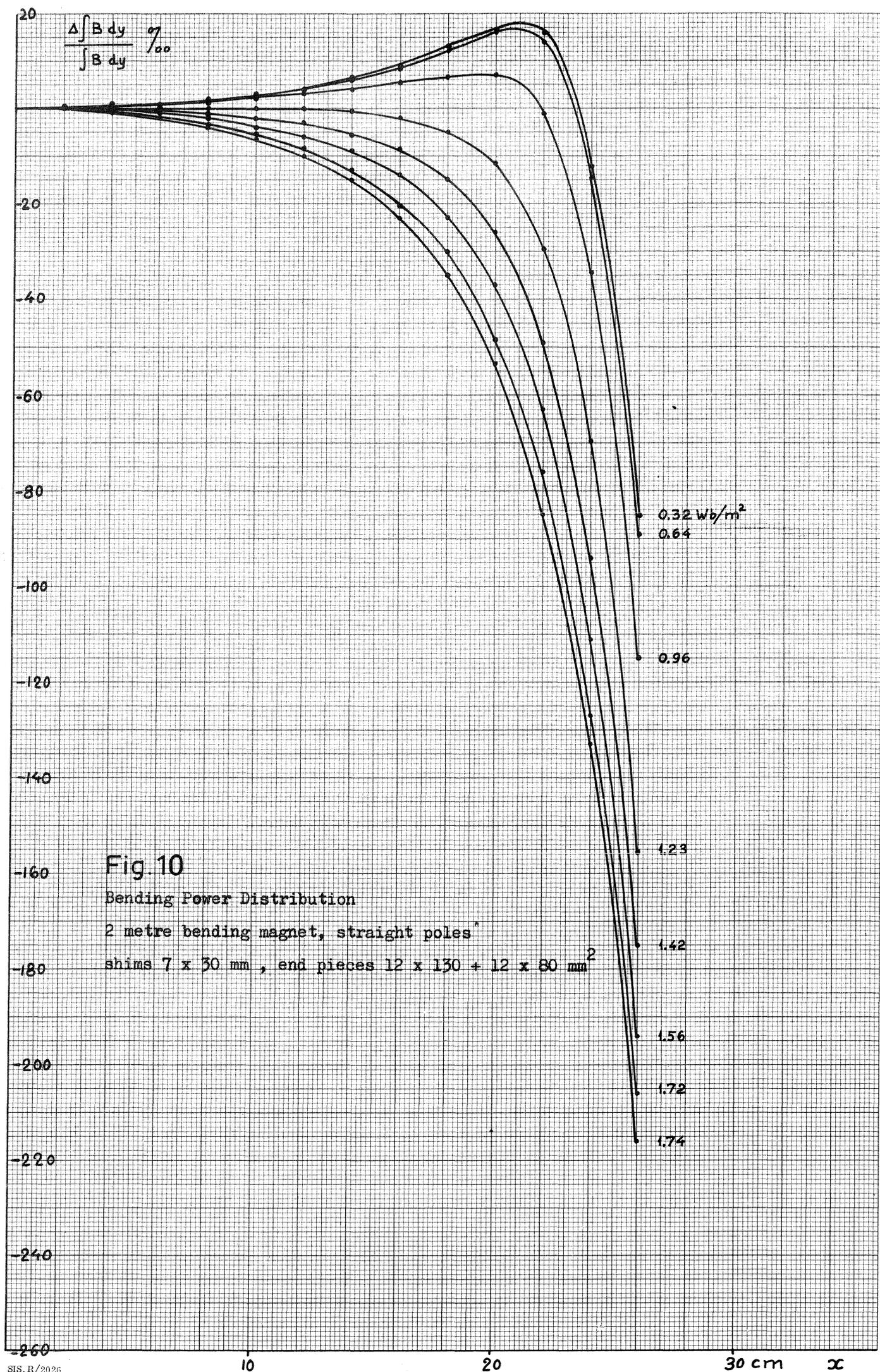


**Fig.9**

Bending Power Distribution

2 metre bending magnet, straight poles

shim 7 x 30 mm, without end pieces

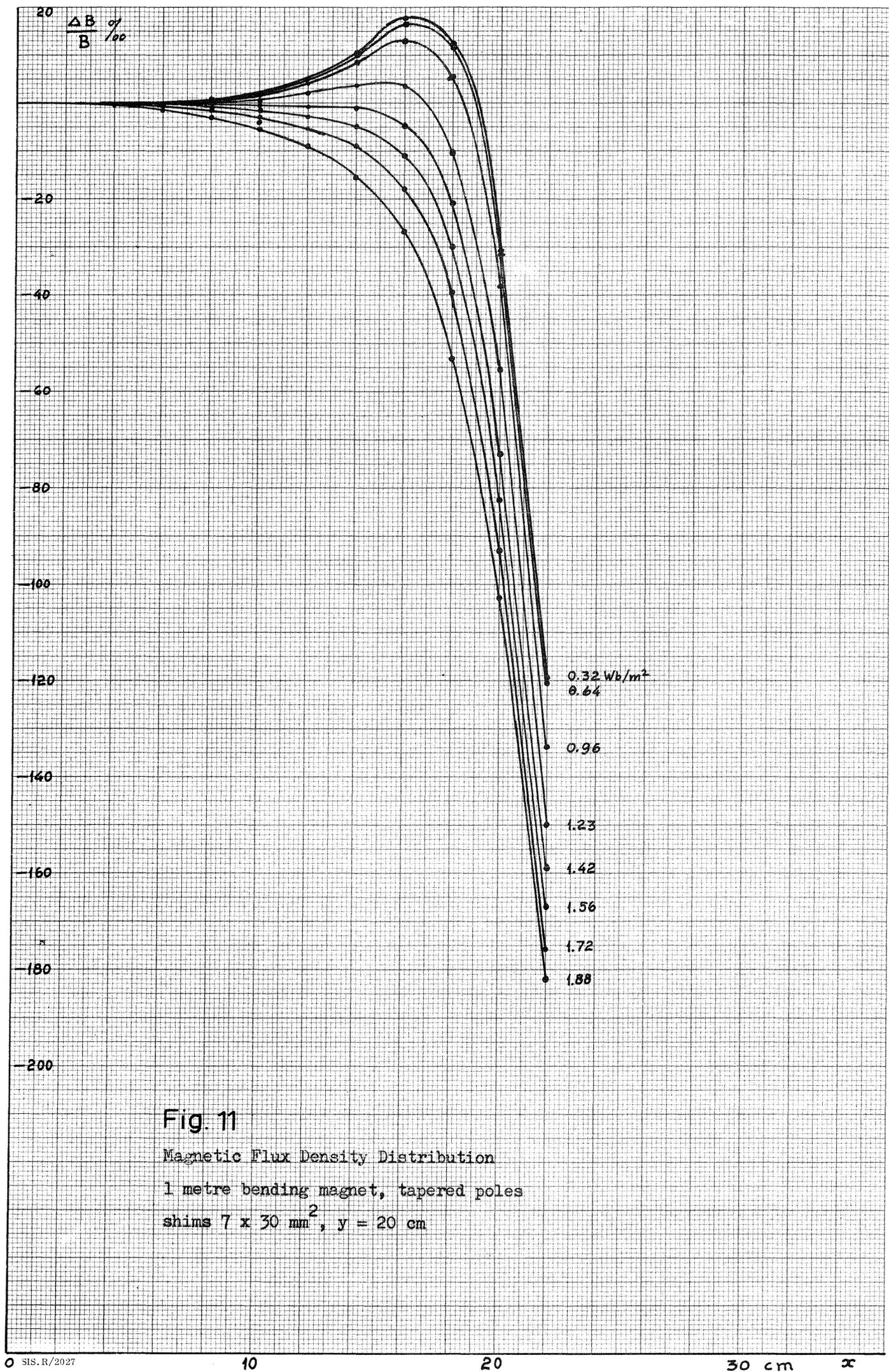


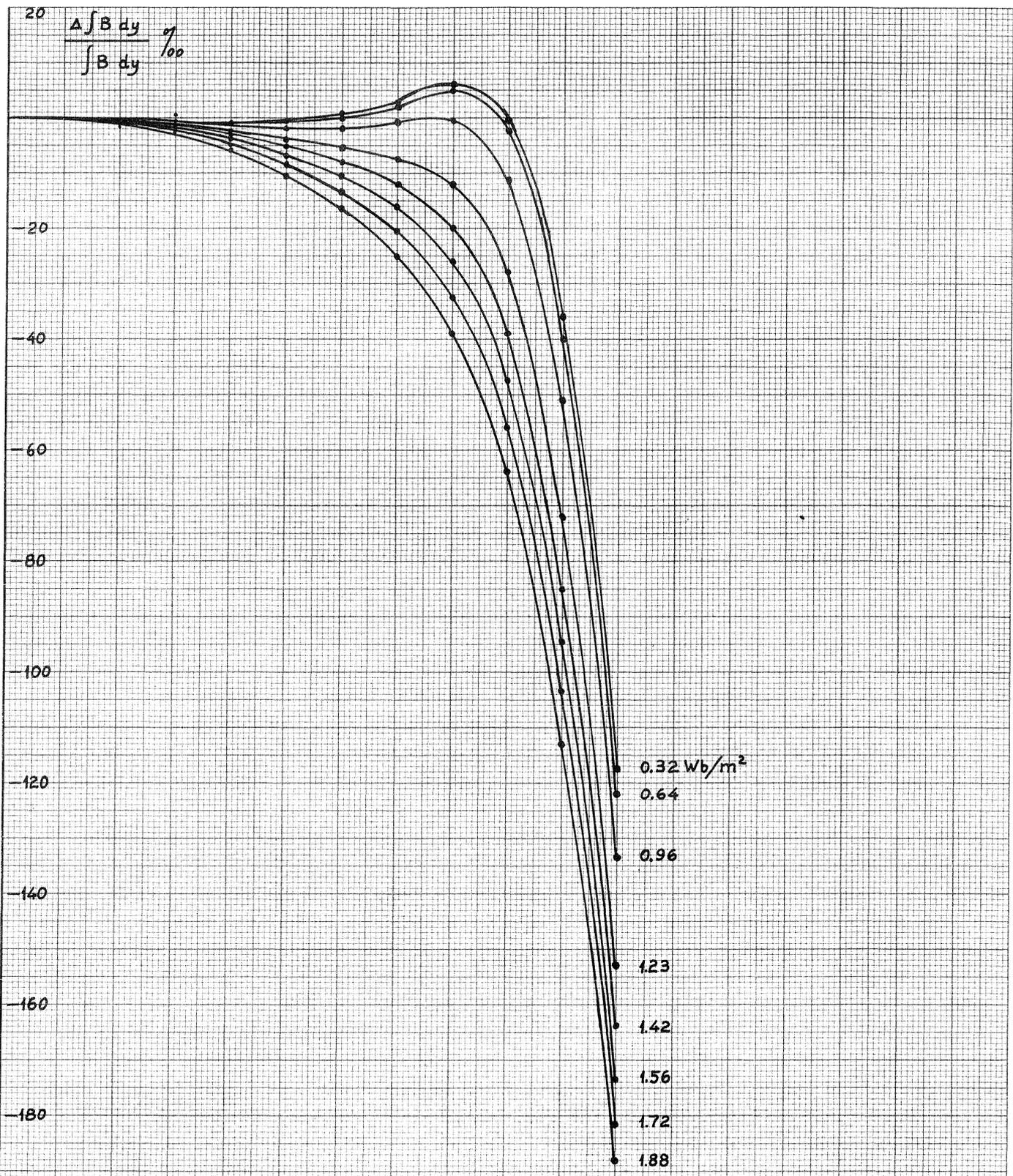
**Fig 10**

Bending Power Distribution

2 metre bending magnet, straight poles

shims 7 x 30 mm, end pieces 12 x 130 + 12 x 80 mm<sup>2</sup>





**Fig. 12**  
 Bending Power Distribution  
 1 metre bending magnet, tapered poles  
 shim 7 x 30 mm<sup>2</sup>, no end piece

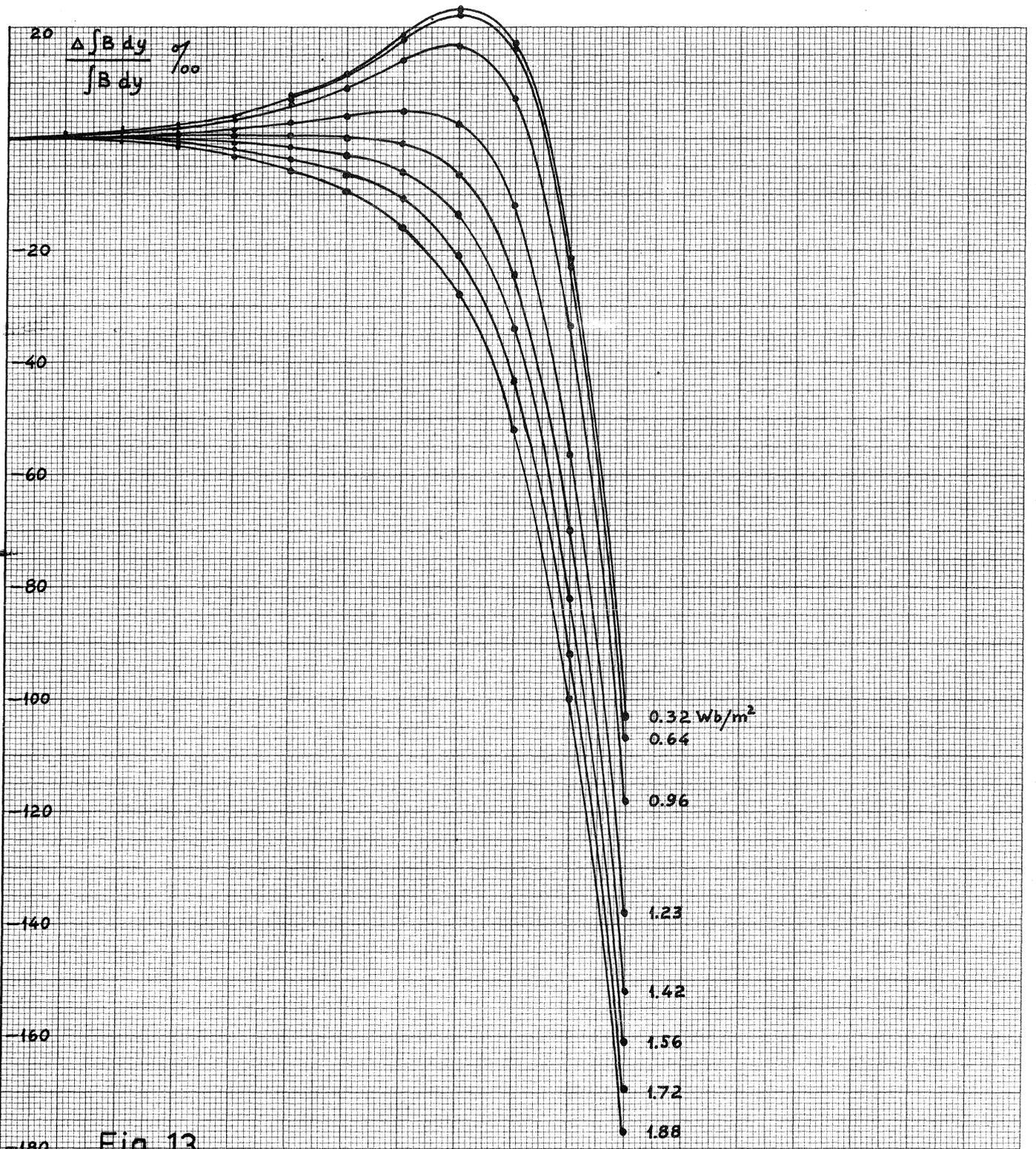
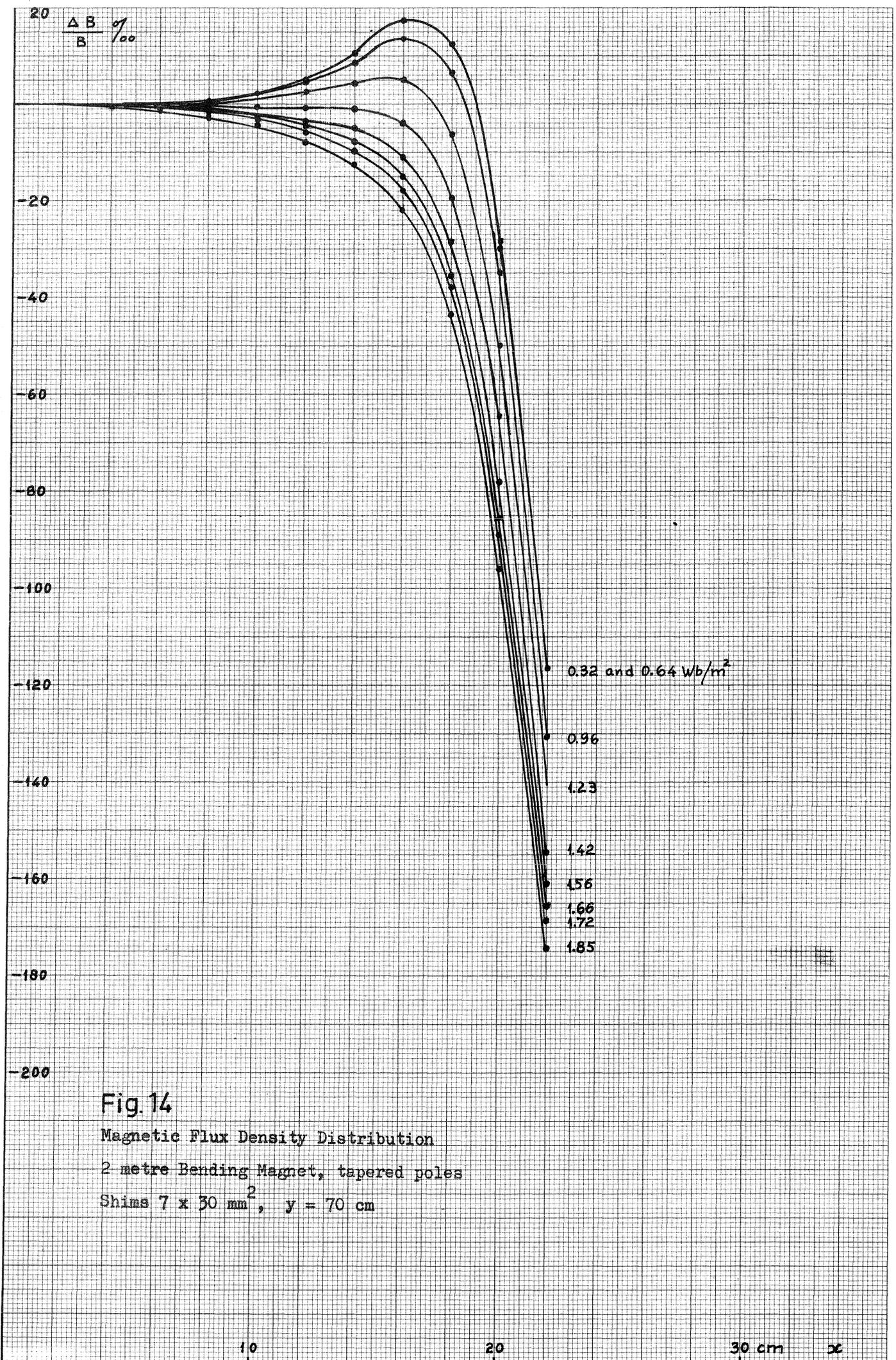


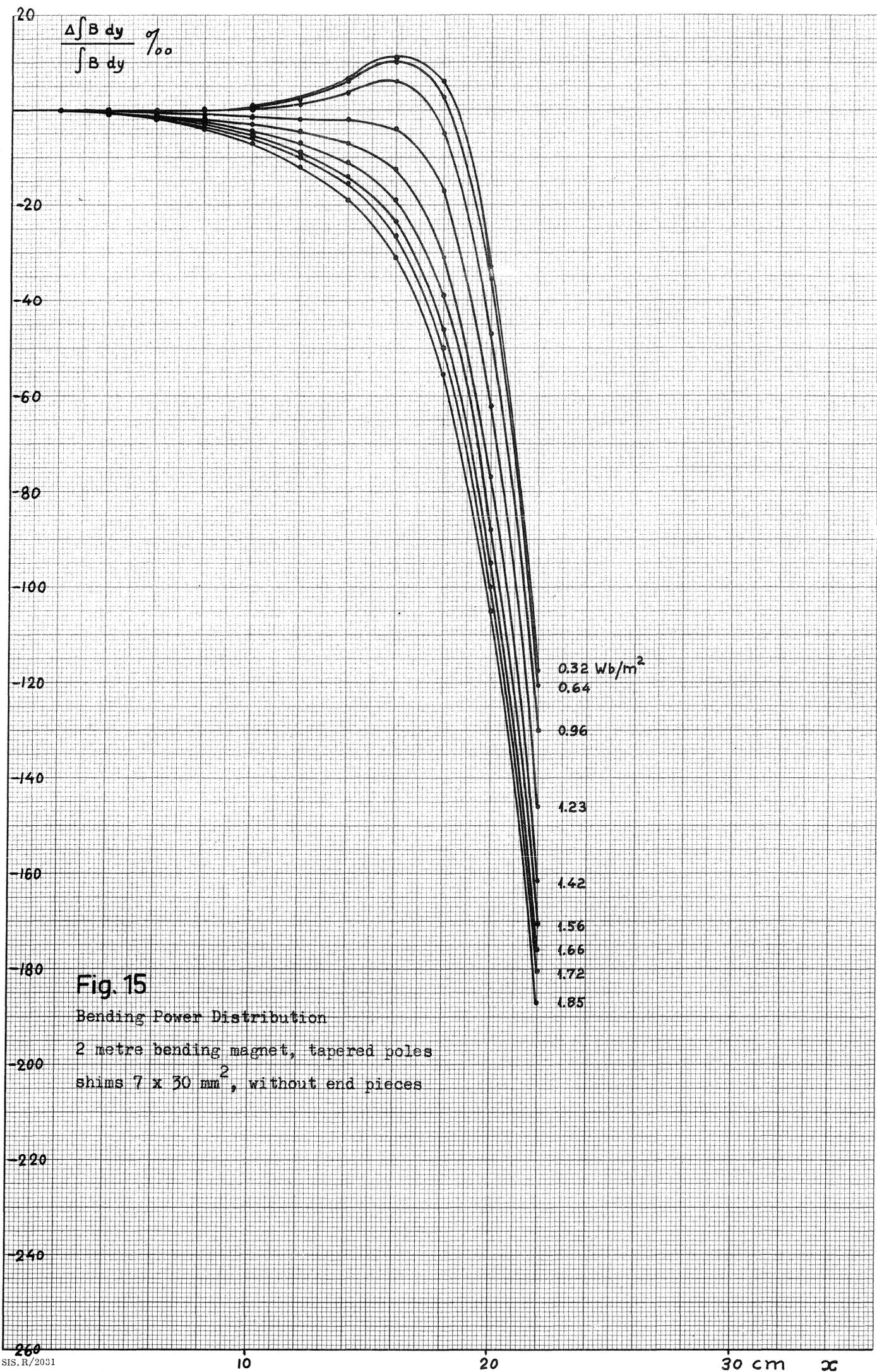
Fig. 13

Bending Power Distribution

1 metre bending magnet, tapered poles

shim 7 x 30 mm<sup>2</sup>, end piece 20 x 130 mm<sup>2</sup>

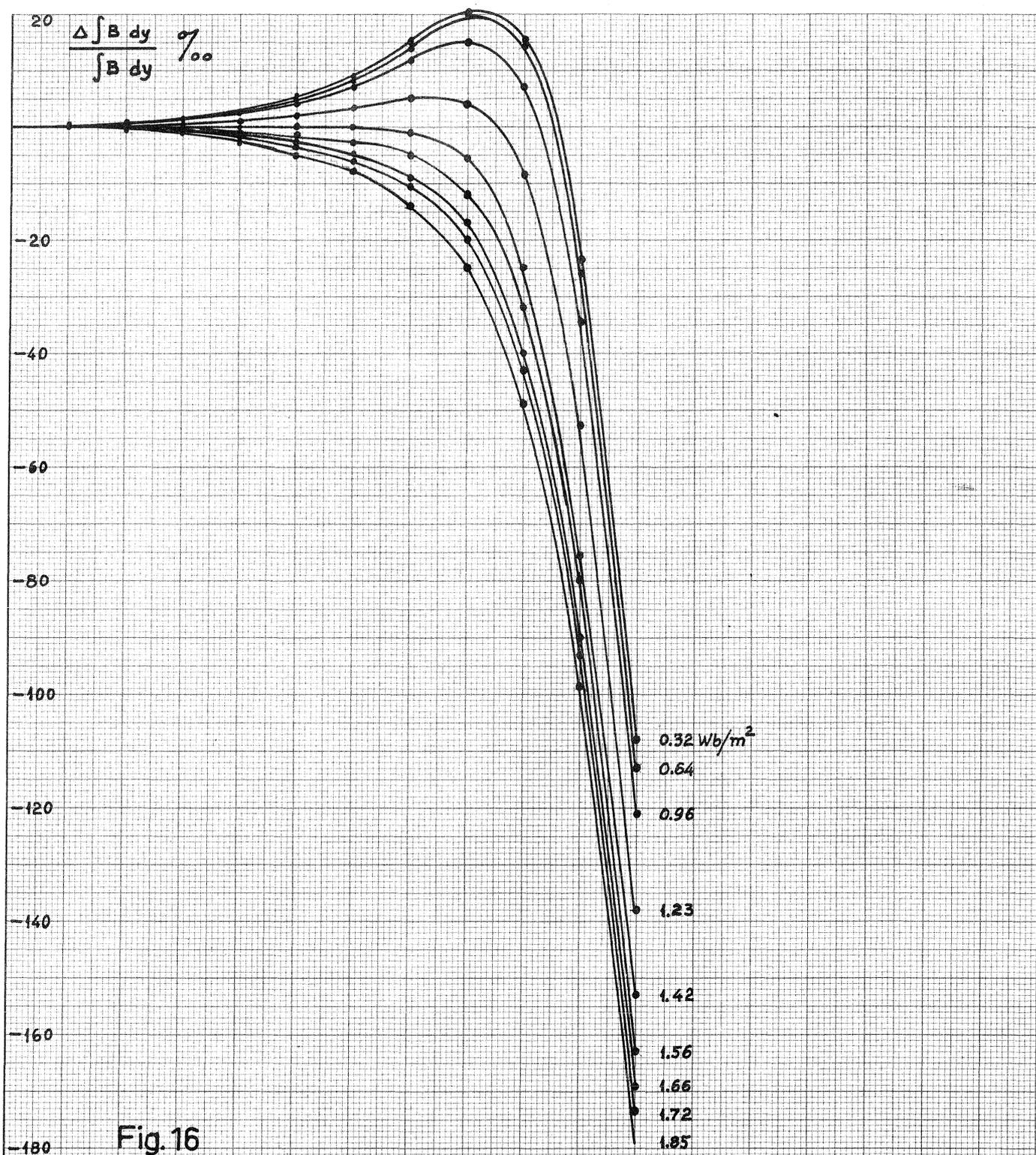




**Fig. 15**

Bending Power Distribution  
 2 metre bending magnet, tapered poles  
 shims  $7 \times 30 \text{ mm}^2$ , without end pieces

- 0.32 Wb/m<sup>2</sup>
- 0.64
- 0.96
- 1.23
- 1.42
- 1.56
- 1.66
- 1.72
- 1.85



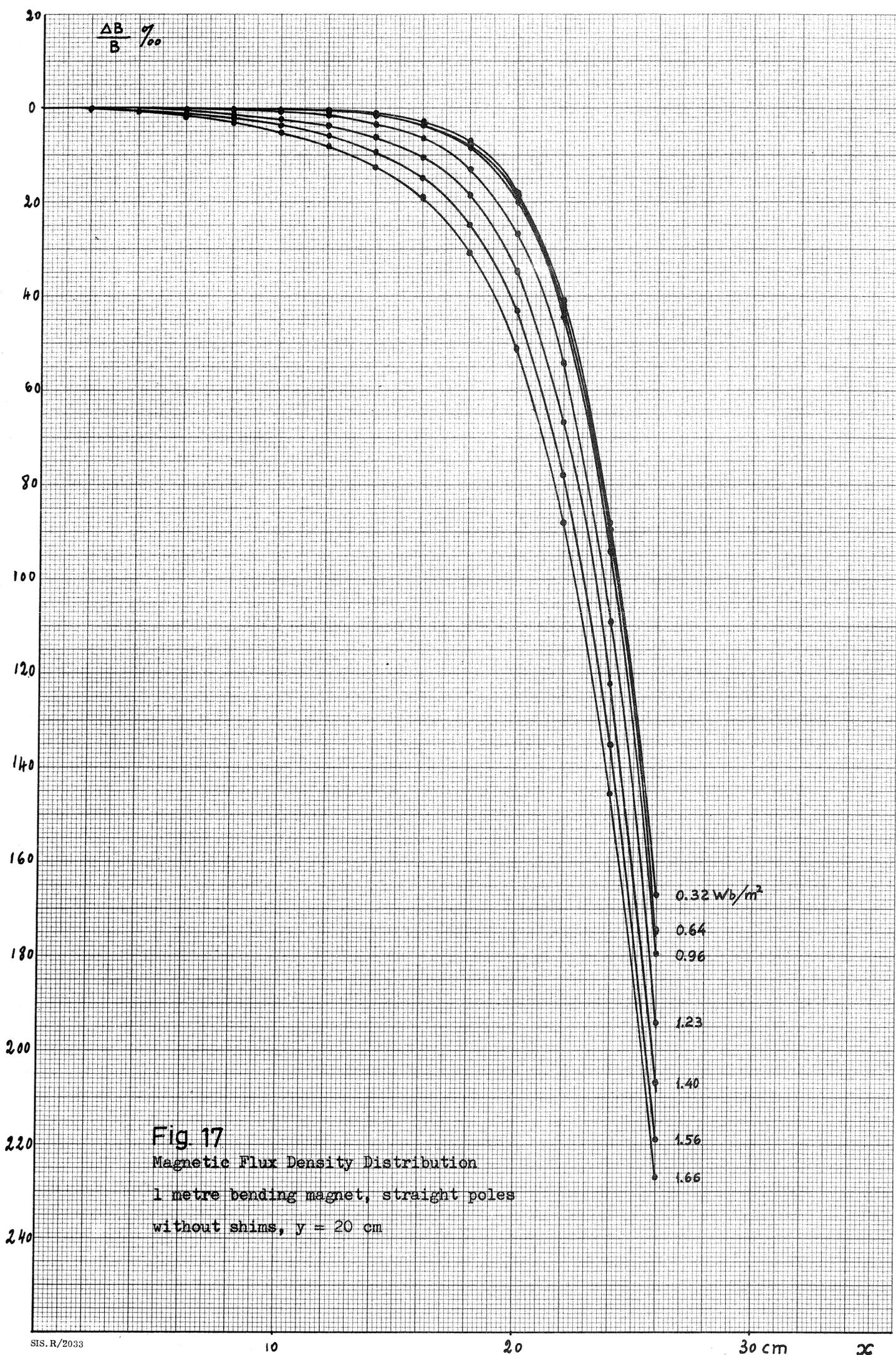
**Fig. 16**

Bending Power Distribution

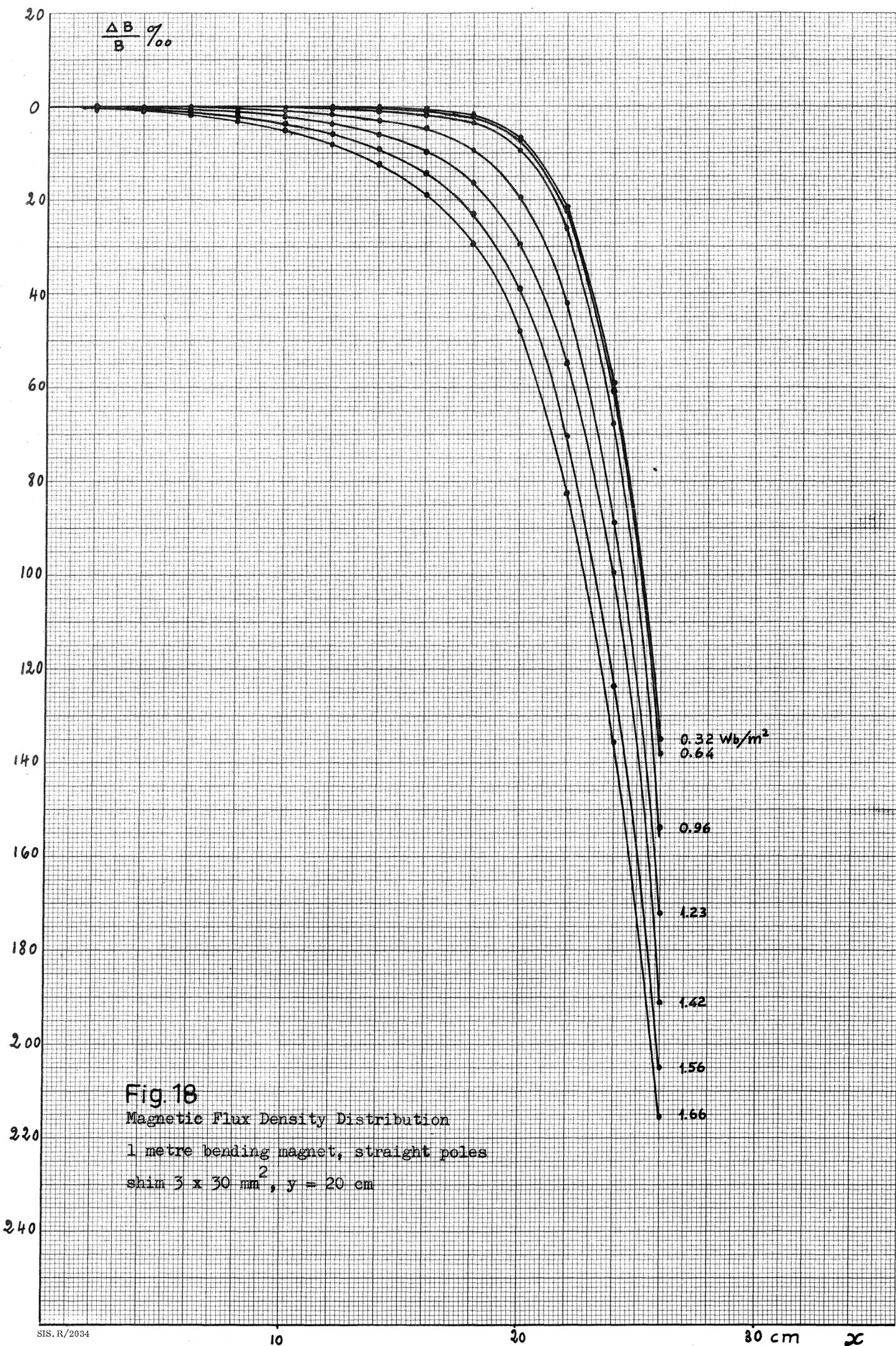
2 metre bending magnet, tapered poles

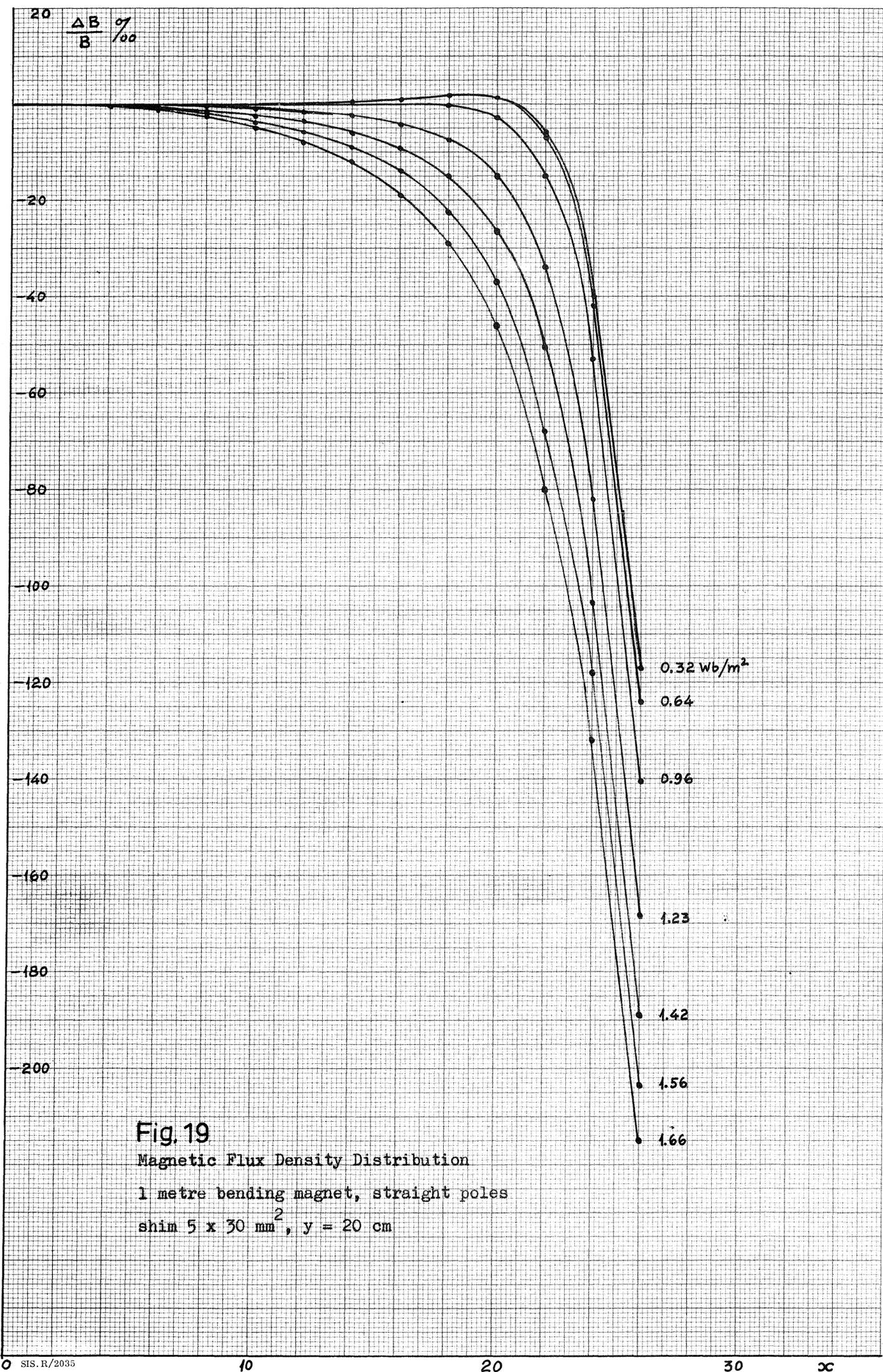
shims 7 x 30 mm<sup>2</sup>, end pieces 20 x 130 mm<sup>2</sup>

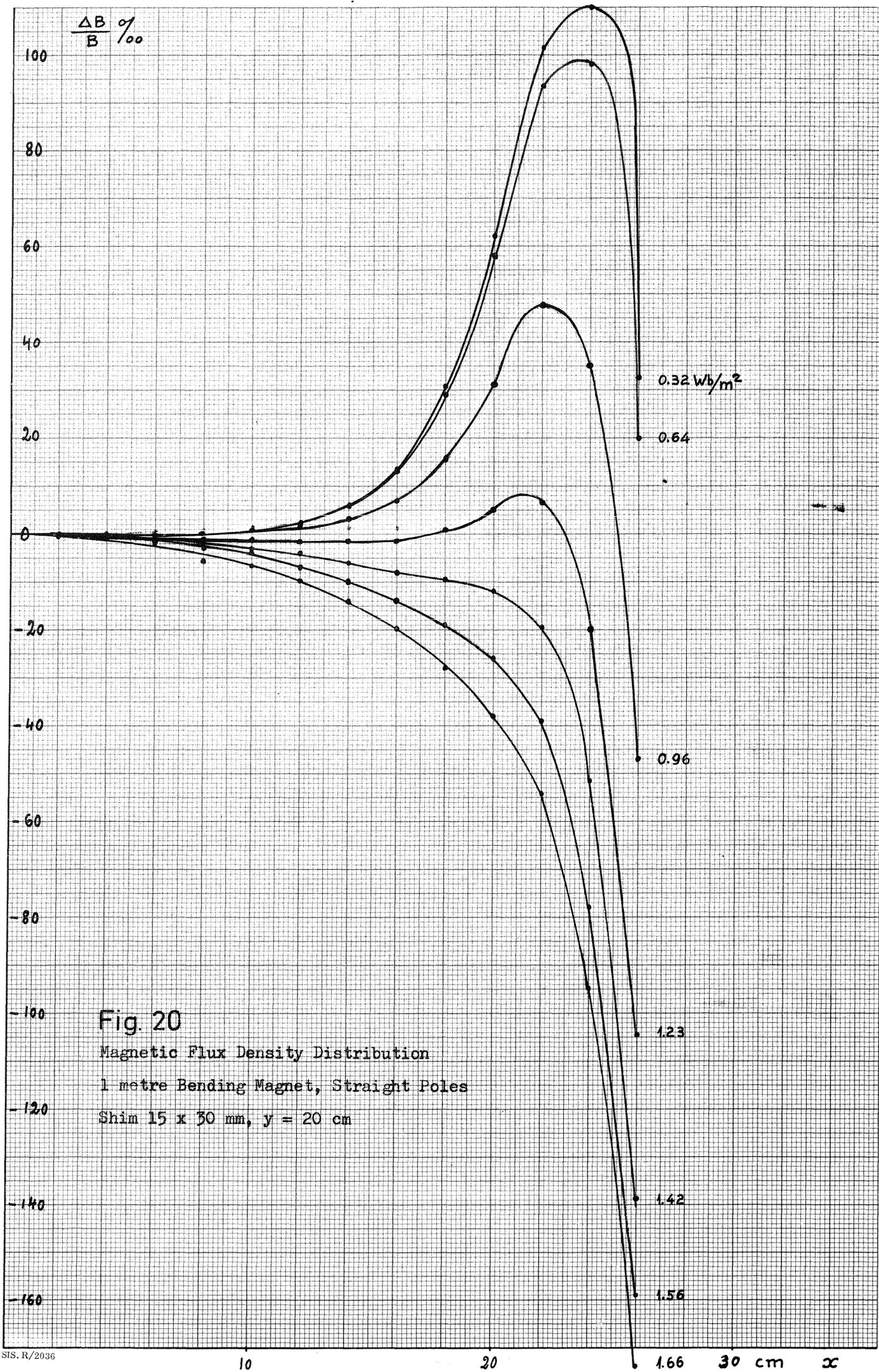
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**Fig. 17**  
 Magnetic Flux Density Distribution  
 1 metre bending magnet, straight poles  
 without shims,  $y = 20$  cm

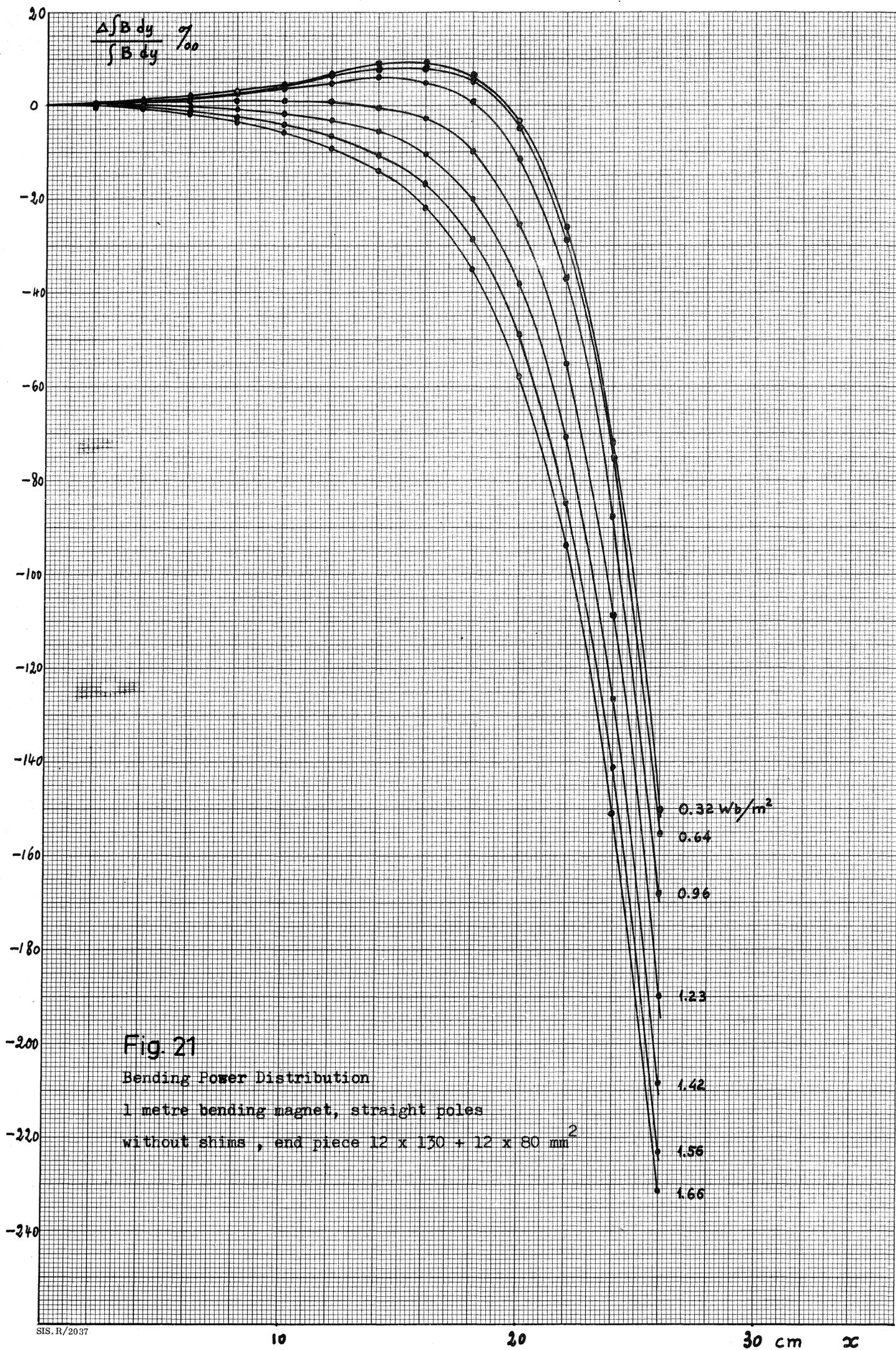


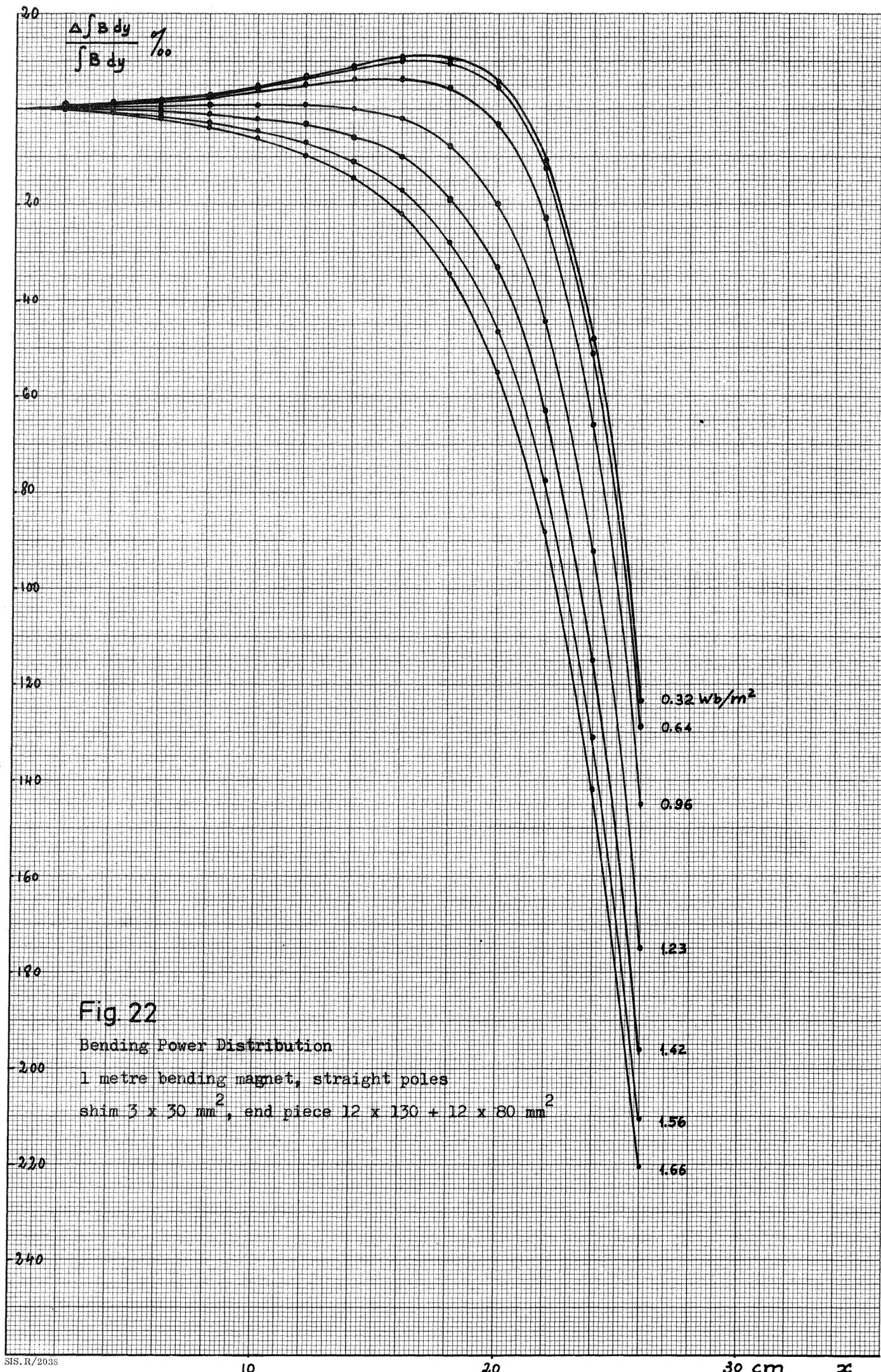




**Fig. 20**

Magnetic Flux Density Distribution  
 1 metre Bending Magnet, Straight Poles  
 Shim 15 x 30 mm,  $y = 20$  cm



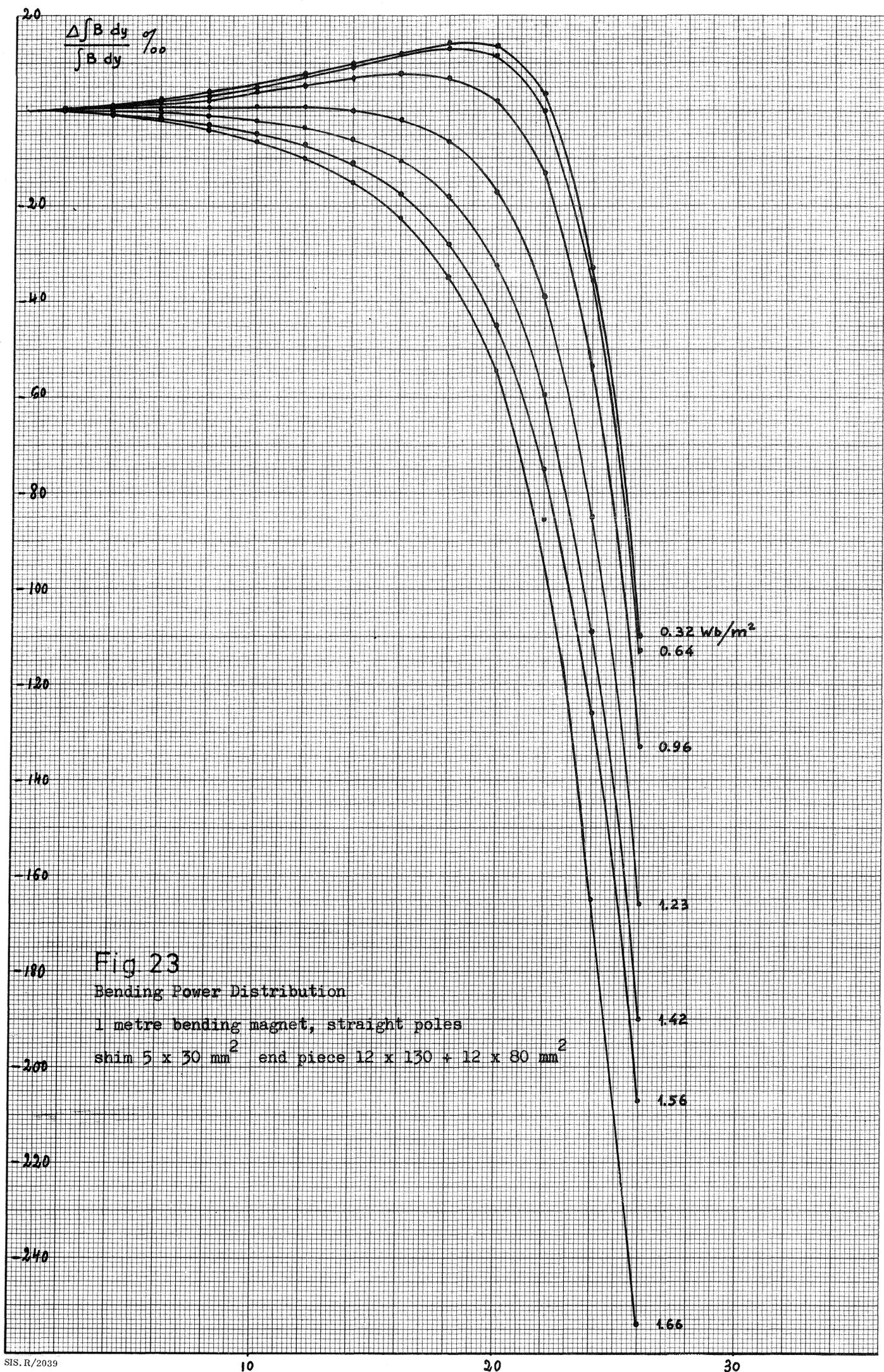


**Fig. 22**

Bending Power Distribution

1 metre bending magnet, straight poles

shim  $3 \times 30 \text{ mm}^2$ , end piece  $12 \times 130 + 12 \times 80 \text{ mm}^2$



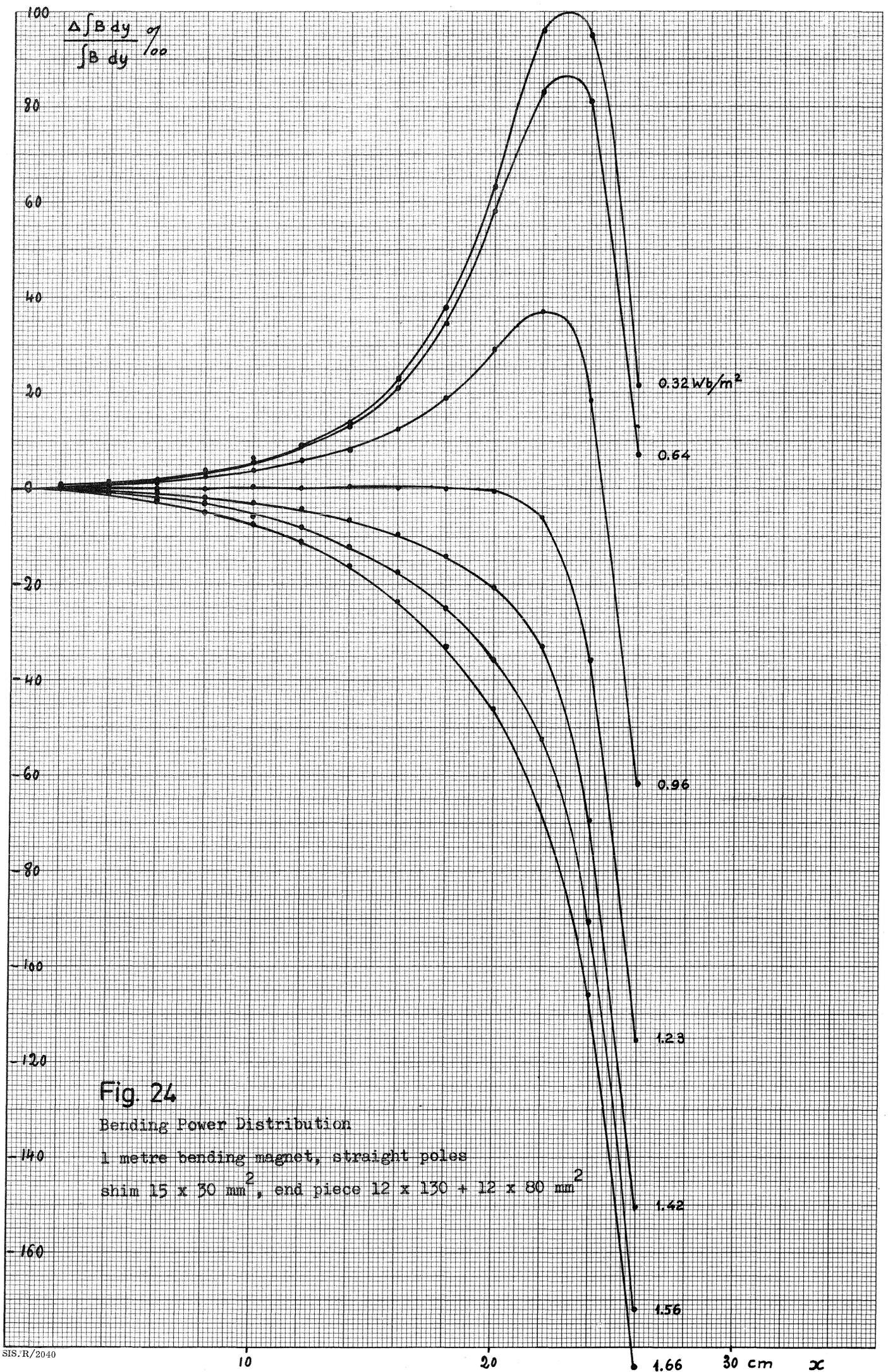
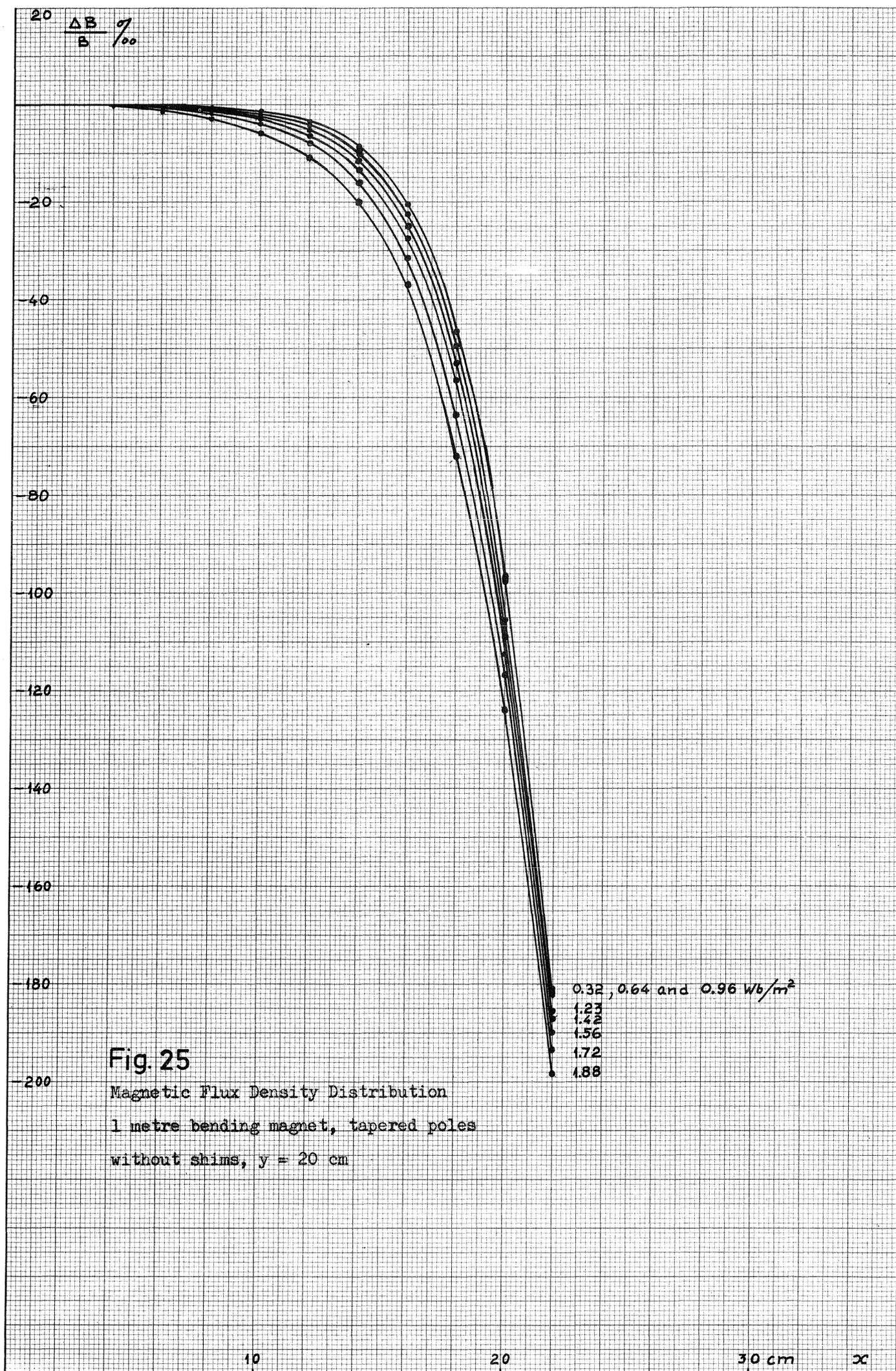


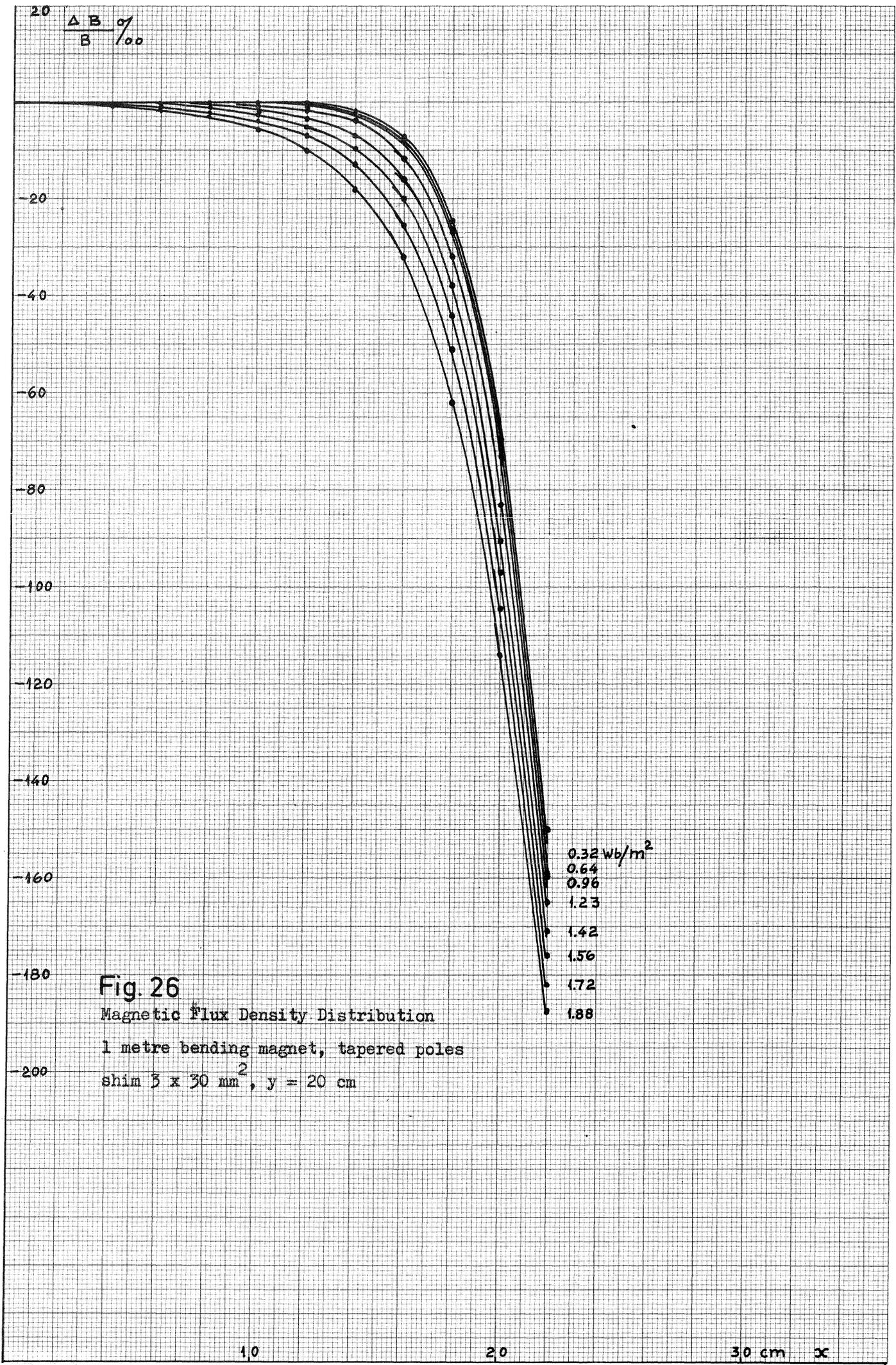
Fig. 24

Bending Power Distribution

1 metre bending magnet, straight poles

shim 15 x 30 mm<sup>2</sup>, end piece 12 x 130 + 12 x 80 mm<sup>2</sup>





**Fig. 26**  
 Magnetic Flux Density Distribution  
 1 metre bending magnet, tapered poles  
 shim 3 x 30 mm<sup>2</sup>, y = 20 cm

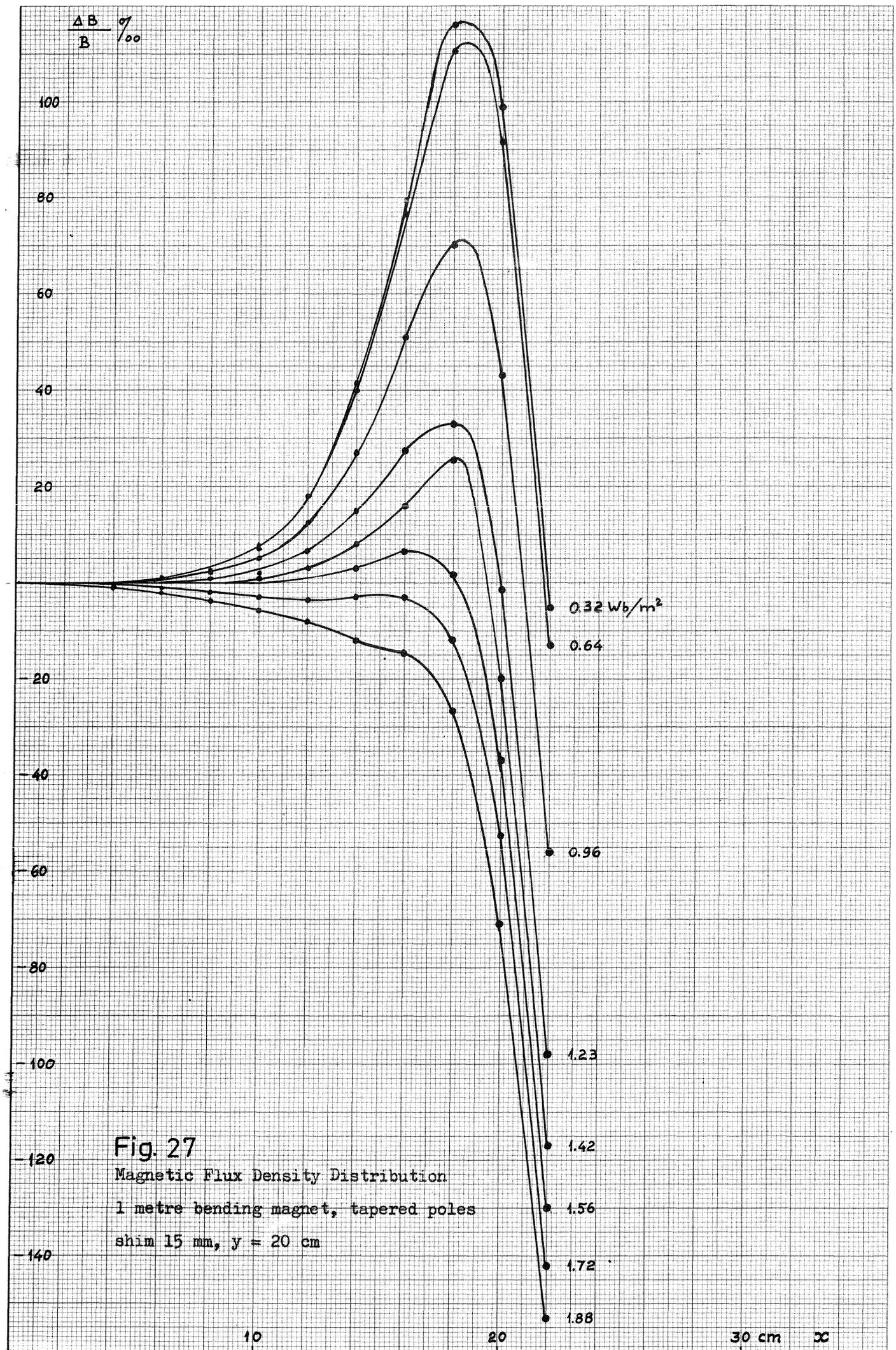
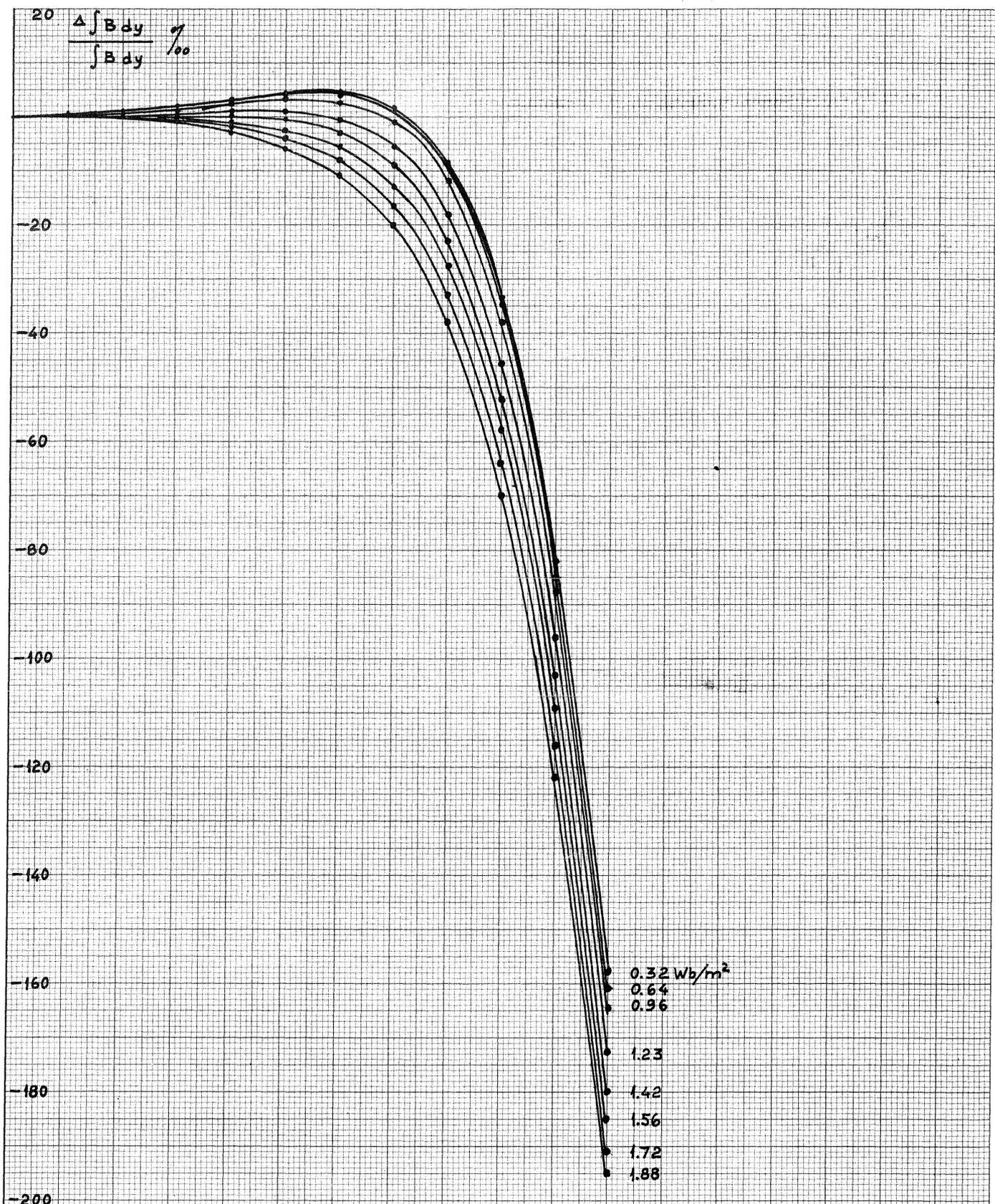
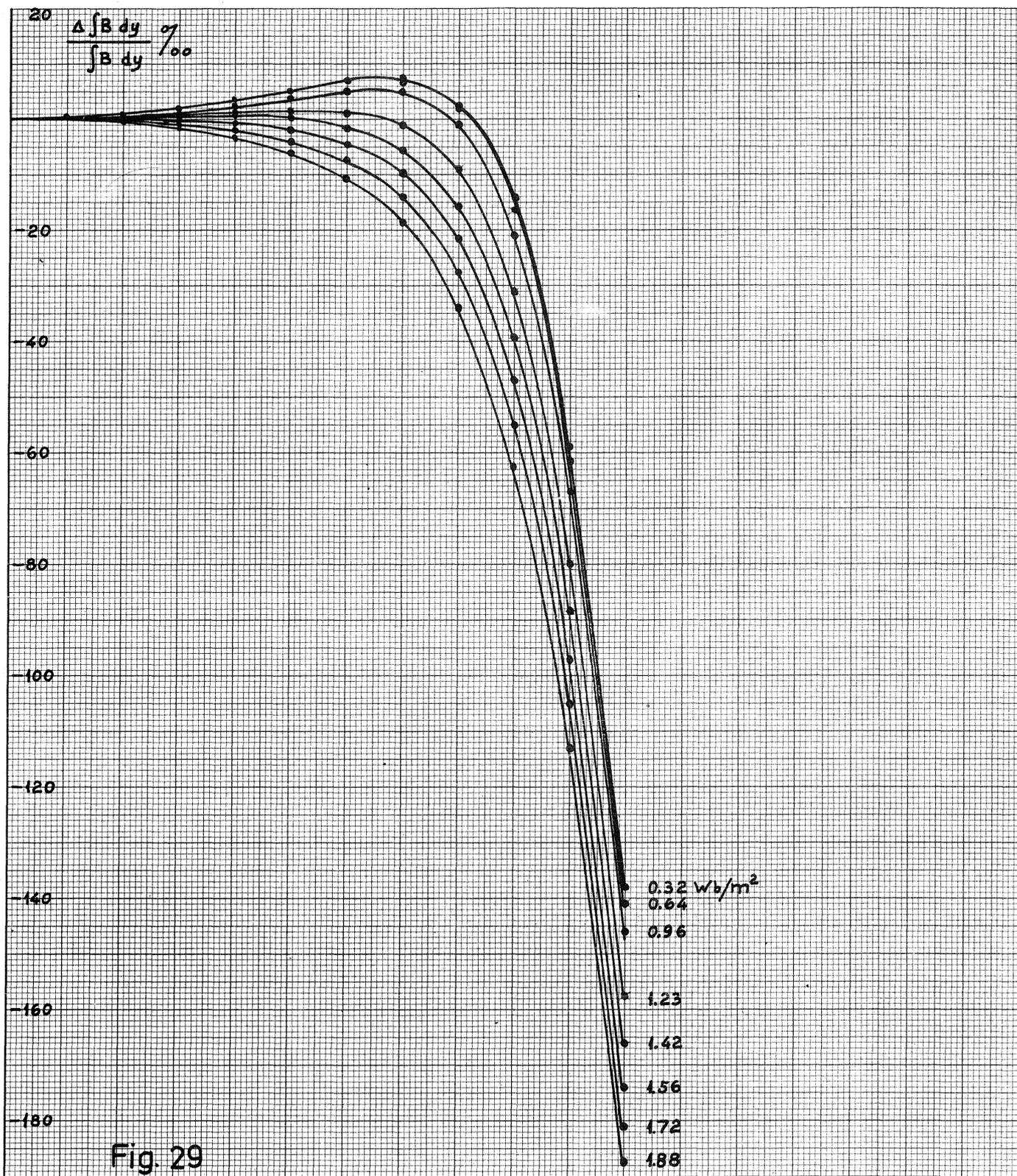


Fig. 27

Magnetic Flux Density Distribution  
 1 metre bending magnet, tapered poles  
 shim 15 mm,  $y = 20$  cm



**Fig. 28**  
 Bending Power Distribution  
 1 metre bending magnet, tapered poles  
 without shims, end piece 20 x 130 mm<sup>2</sup>



**Fig 29**

Bending Power Distribution

1 metre bending magnet, tapered poles  
 shim  $3 \times 30 \text{ mm}^2$ , end piece  $20 \times 130 \text{ mm}^2$

