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Elastic Distortion Calculations at NPL on a PTB 400 MPa Pressure Balance as part of EUROMET Project 256

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ABSTRACT

This report details the results, obtained at the National Physical Laboratory, of the investigation into the elastic distortion of a PTB 400 MPa piston cylinder unit. It forms a progress report on NPL's participation in the EUROMET Project 256.

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Approved on behalf of Chief Executive, NPL,
by Prof A R Colclough, Head, Division of Mechanical and Optical Metrology

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1 INTRODUCTION

EUROMET Project 256 is a collaboration between NPL, IMGC, PTB and LNE on the calculation of elastic distortion of piston-cylinder assemblies in pressure balances and in hydraulic amplifiers in force machines.¹ As part of this project it was decided at the 4th EUROMET Mass and Related Quantities meeting in March 1993 that the two iterative methods for the calculation of elastic distortion of piston cylinder units, finite element analysis at the NPL and analytical at IMGC, would be compared using two piston-cylinder designs.

It was agreed that two piston-cylinder units would be modelled:

- A 400 MPa capacity, free deformation, nominal effective area 8.4 mm², piston and cylinder of tungsten carbide belonging to PTB.
- A 200 MPa capacity, free deformation, nominal effective area 50 mm², piston and cylinder of tungsten carbide belonging to LNE.

This report concerns the NPL characterisation of the 400 MPa unit supplied by PTB. It was agreed that the calculation of elastic distortion would be carried out at two pressures, 120 MPa and 200 MPa, from data about the unit supplied by PTB. This report also includes results for 80, 160, 240, 300 and 400 MPa pressures. The modelling was undertaken on a Sun Work Station using a finite element analysis package developed by the NPL in conjunction with City University based on the work of N Samaan².

2 DESCRIPTION OF THE PTB-400 MPa PRESSURE BALANCE

The PTB-400 MPa pressure balance is a free deformation, simple design piston-cylinder and a sketch is shown in Figures 1 and 2.

The piston and cylinder are made of tungsten carbide ($E = 6.08 \times 10^5$ and $\mu = 0.212$) and have a nominal effective area of 8.4 mm². From absolute diameter measurements the mean clearance in the working position is 0.287 μm .

PTB ascribe a distortion coefficient of $\lambda = 0.725 \times 10^{-6} \text{ MPa}^{-1}$ to the unit.

The piston is at its working position when the bottom surface of the piston is 35.2 mm below the top surface of the cylinder. The piston-cylinder combination has an engagement length of 25.4 mm.

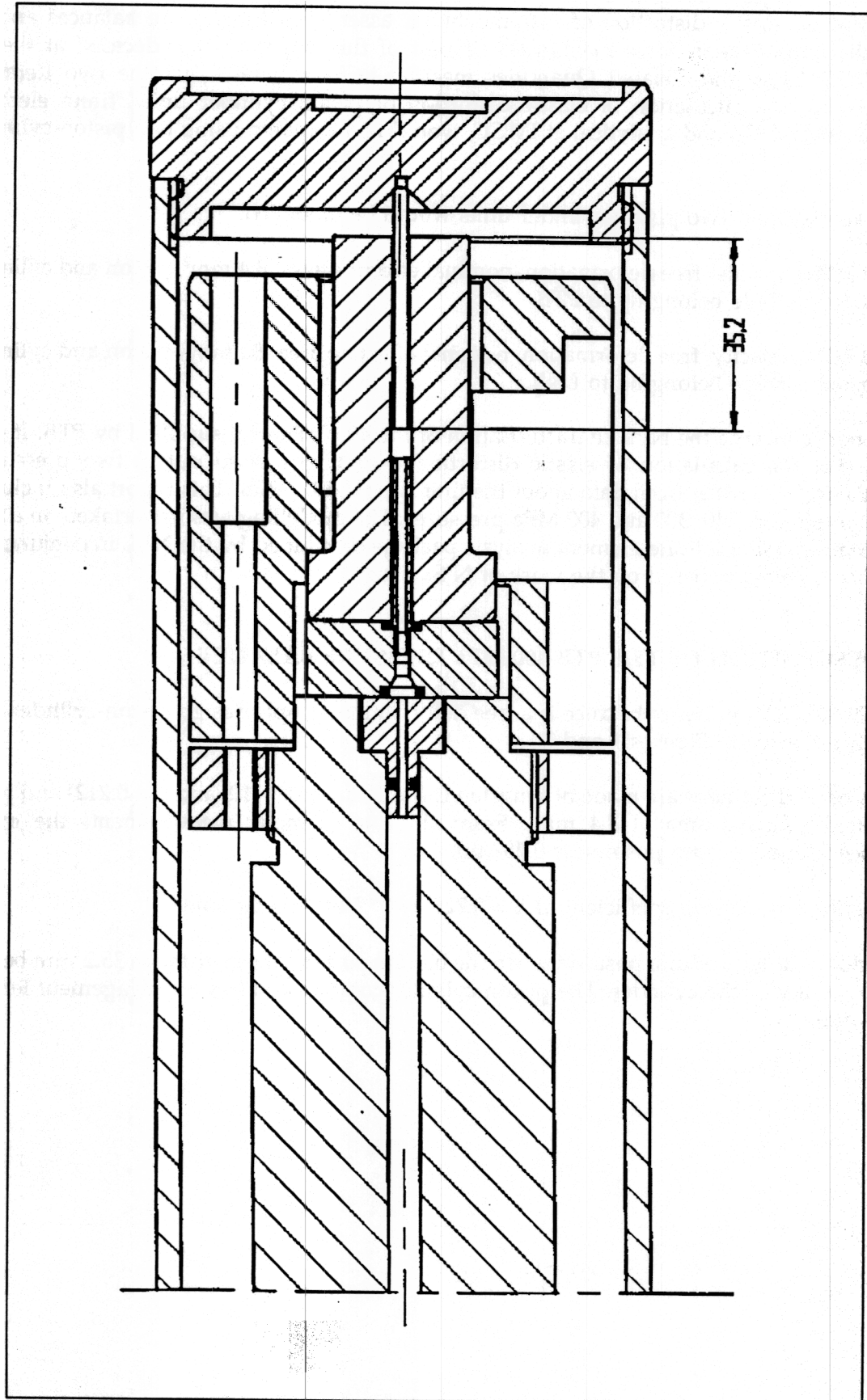


Figure 1 Piston-cylinder sketch (provided by PTB)

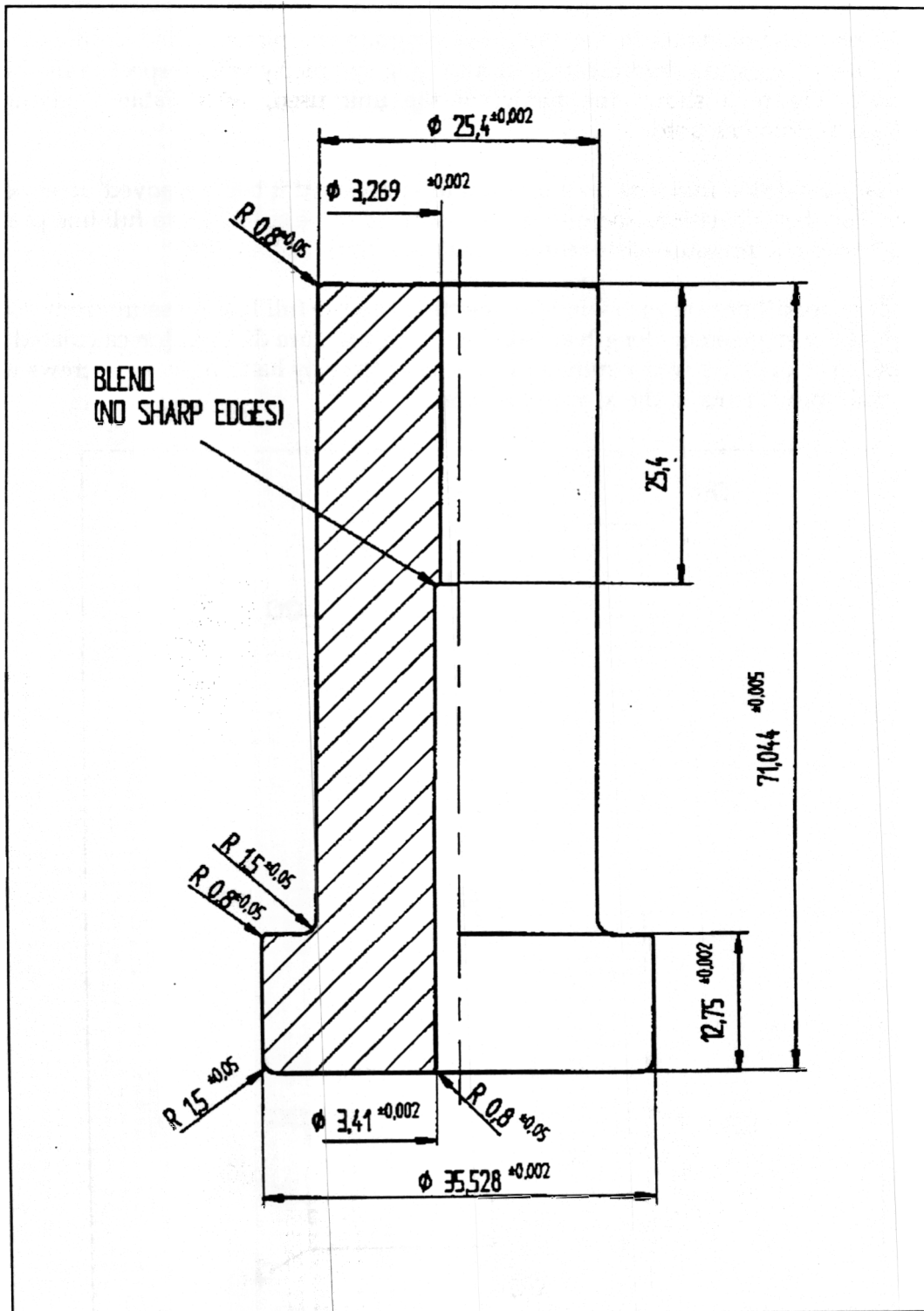


Figure Cylinder dimensions (provided by PTB)

3 MODELLING OF THE PTB-400 MPa PISTON-CYLINDER UNIT

In order to be accommodated in the computer program the piston-cylinder unit was first modelled. This process has the limitation of imposing symmetry with respect to the piston-cylinder axis. Figure 3 shows the model of the unit used, with Table 1 giving the dimensions/co-ordinates used.

The boundary condition imposed on the piston top prevented it being "moved" in either the x or y axis. For the calculations the piston was assumed to be subjected to full line pressure below "AP" with the pressure distribution calculated from "AP" to "BP".

The boundary conditions on the cylinder subjected it to the full line pressure from "GC" to the bottom of the engagement length at "AC", with the pressure distribution calculated from "AC" to "BC". The cylinder was assumed to be held in place by hand tightened screws which allowed small movements in the x, y and z axes.

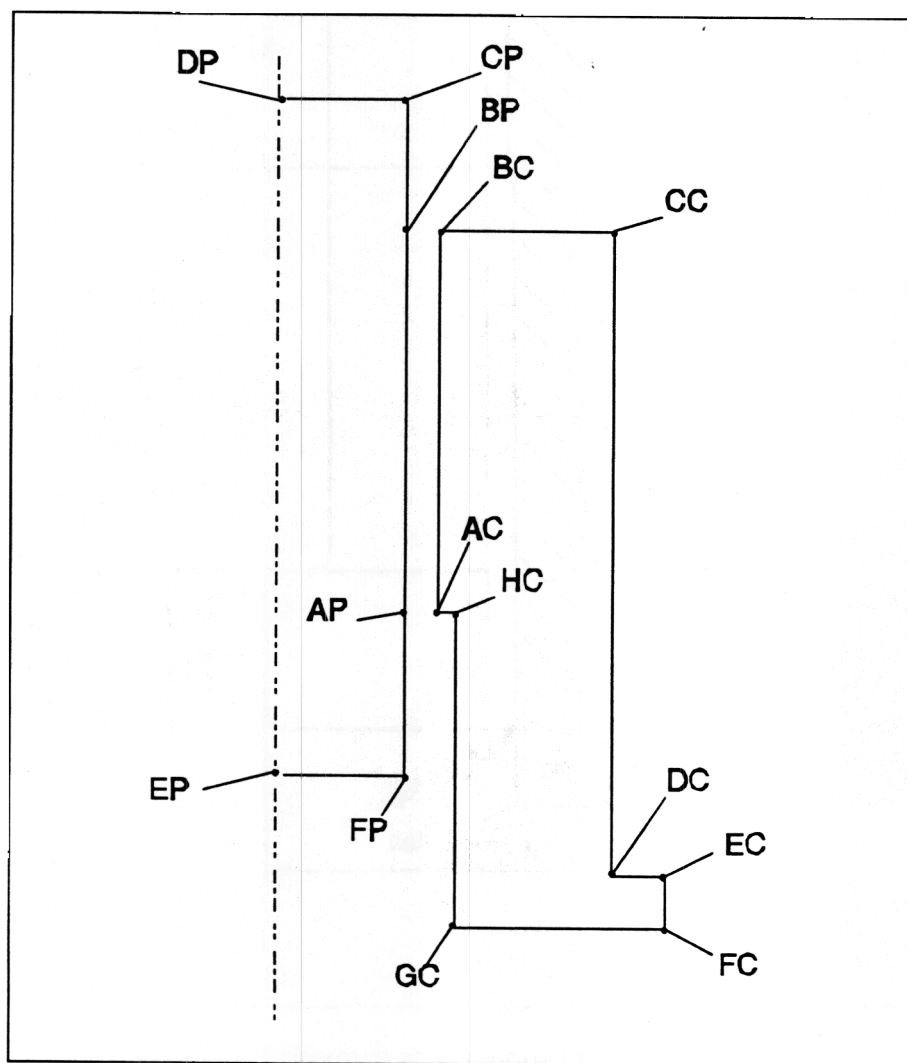


Figure 3 Piston-cylinder model

Table 1 Co-ordinates for piston-cylinder model

CYLINDER	<u>X-AXIS</u> mm	<u>Y-AXIS</u> mm
AC	1.6345	45.644
BC	1.6345	71.044
CC	12.700	71.044
DC	12.700	12.750
EC	17.764	12.750
FC	17.764	0
GC	1.705	0
HC	1.705	45.644
PISTON	<u>X-AXIS</u> mm	<u>Y-AXIS</u> mm
AP	1.6345	45.644
BP	1.6345	71.044
CP	1.6345	75
DP	0	75
EP	0	35.844
FP	1.6345	35.844

4 CALCULATION OF ELASTIC DISTORTION

Using the model detailed in section 3 the elastic distortion and fall rates were calculated for several pressures. All calculations were carried out assuming di-ethyl-hexyl-sebacate oil, the viscosity (η) being taken as:

$$\log \eta + 1.2 = (\log \eta_0 + 1.2) (1 + p/200)^z$$

where ambient viscosity (η_0) = 21.1 mPa.s and the viscosity exponent (z) = 0.55.

Table 2 shows the elastic distortion of the balance and the fall rates calculated for sebacate oil and an initial radial clearance of 0.287 μm .

Table 2 Elastic distortion and fall-rate results

<u>Pressure</u> MPa	<u>Distortion (λ)</u> ppm/MPa	<u>Fall rate</u> mm/min
80	0.718	0.05
120	0.719	0.07
160	0.721	0.15
200	0.723	0.20
240	0.724	0.26
300	0.725	0.34
400	0.725	0.45

The radial clearance over the engagement length was found to vary from 0.259 μm to 0.863 μm at 120 MPa and from 0.262 μm to 1.247 μm at 200 MPa. A graph of gap against displacement up the engagement length is shown in Figure 4 for 120 MPa and Figure 5 for 200 MPa.

The pressure profile in the engagement length is shown in Figure 6 for 120 MPa and Figure 7 for 200 MPa. Figures 4 to 7 can be found at the end of this report. "DAE(Norm)" is the normalised distance along the engagement length.

5 RADIAL CLEARANCE AND OIL DEPENDENCE

The initial radial clearance of the balance was taken to be 0.287 μm . Two further calculations were carried out at 120 MPa and 200 MPa with this reduced by 2.5%. These showed an increase in λ of less than 0.1% and a decrease in the fall rate of 2.5% at 120 MPa and 3.5% at 200 MPa.

Further calculations were performed using a different mineral oil with a viscosity exponent (z) of 0.67. These showed an oil dependence with λ decreasing by 0.25% at 120 MPa and by 0.52% at 200 MPa. The fall-rate for this oil was 30% lower at 120 MPa and 50% lower at 200 MPa.

6 CONCLUSIONS

Using the data provided, the λ values for this piston-cylinder calculated using finite-element-analysis were found to be 0.719 ppm/MPa at 120 MPa and 0.723 ppm/MPa at 200 MPa.

7 REFERENCES

1 Agreed EUROMET Project 256, Coordinator GF Molinar, IMGC, 29 March 1993

2 N D Samaan. PhD Thesis, Mathematical modelling of instruments for pressure measurement, City University, London 1990.

8 PRESSURE AND GAP PROFILES

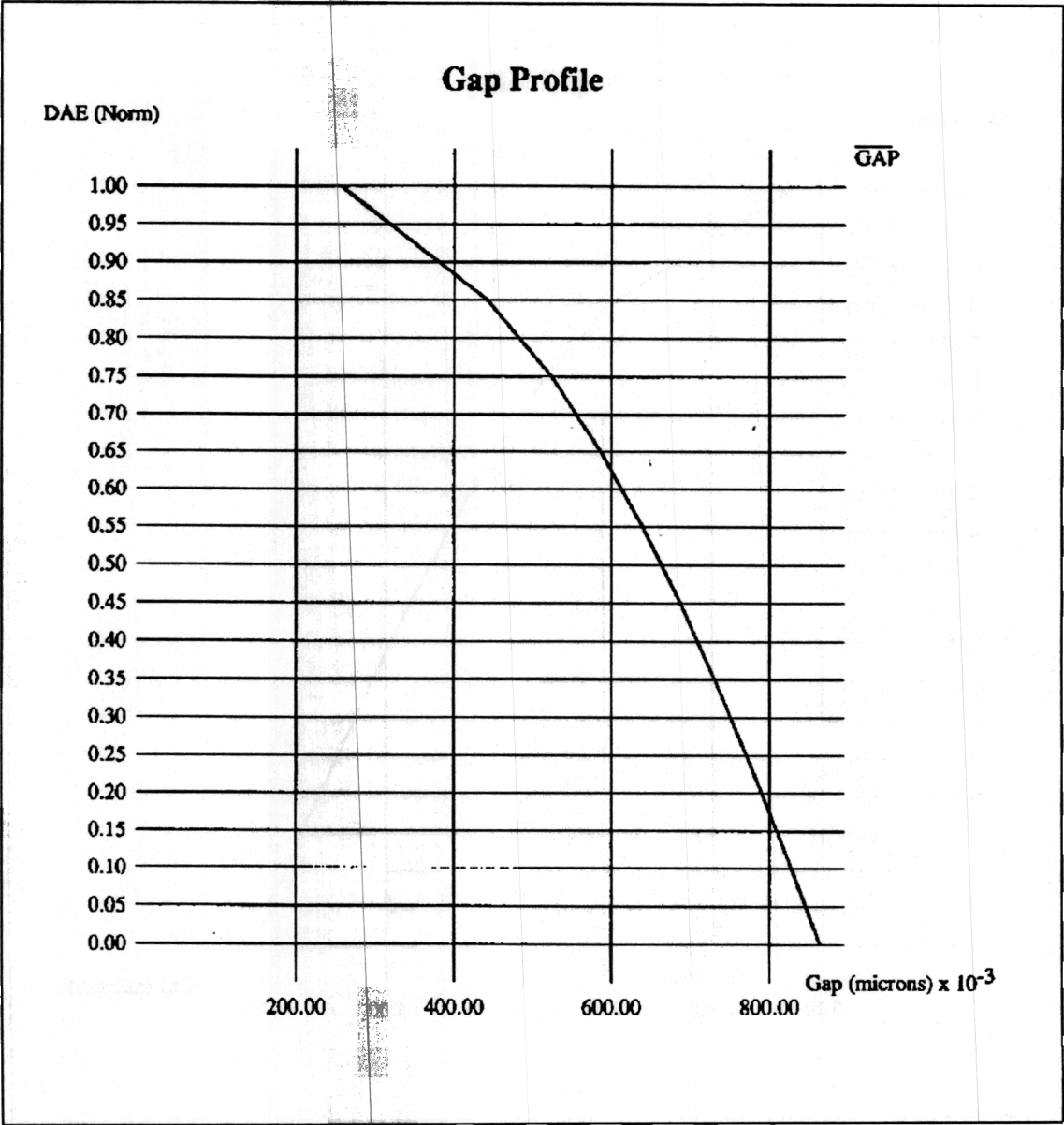


Figure 4 Gap profile at 120 MPa

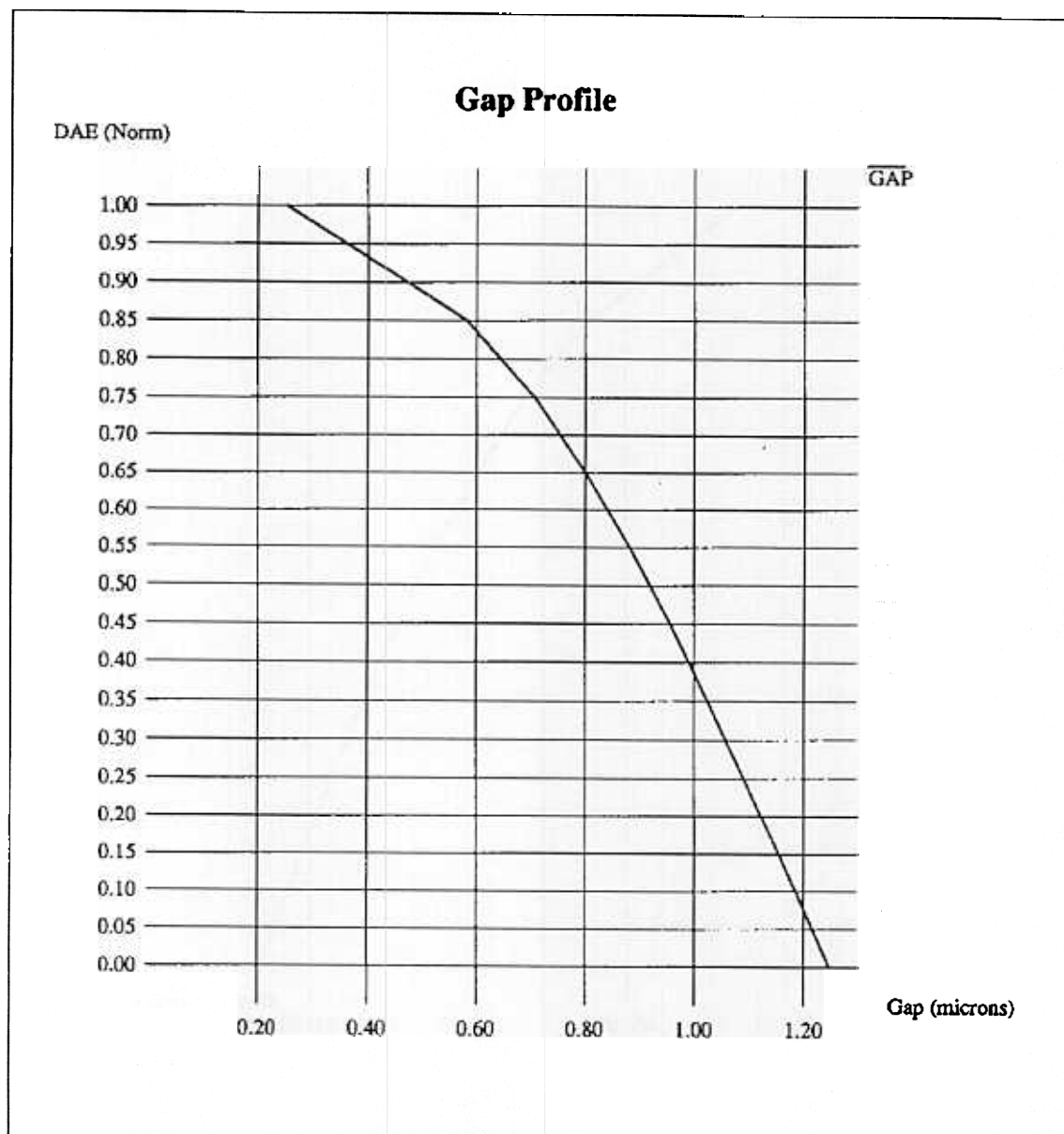


Figure 5 Gap profile at 200 MPa

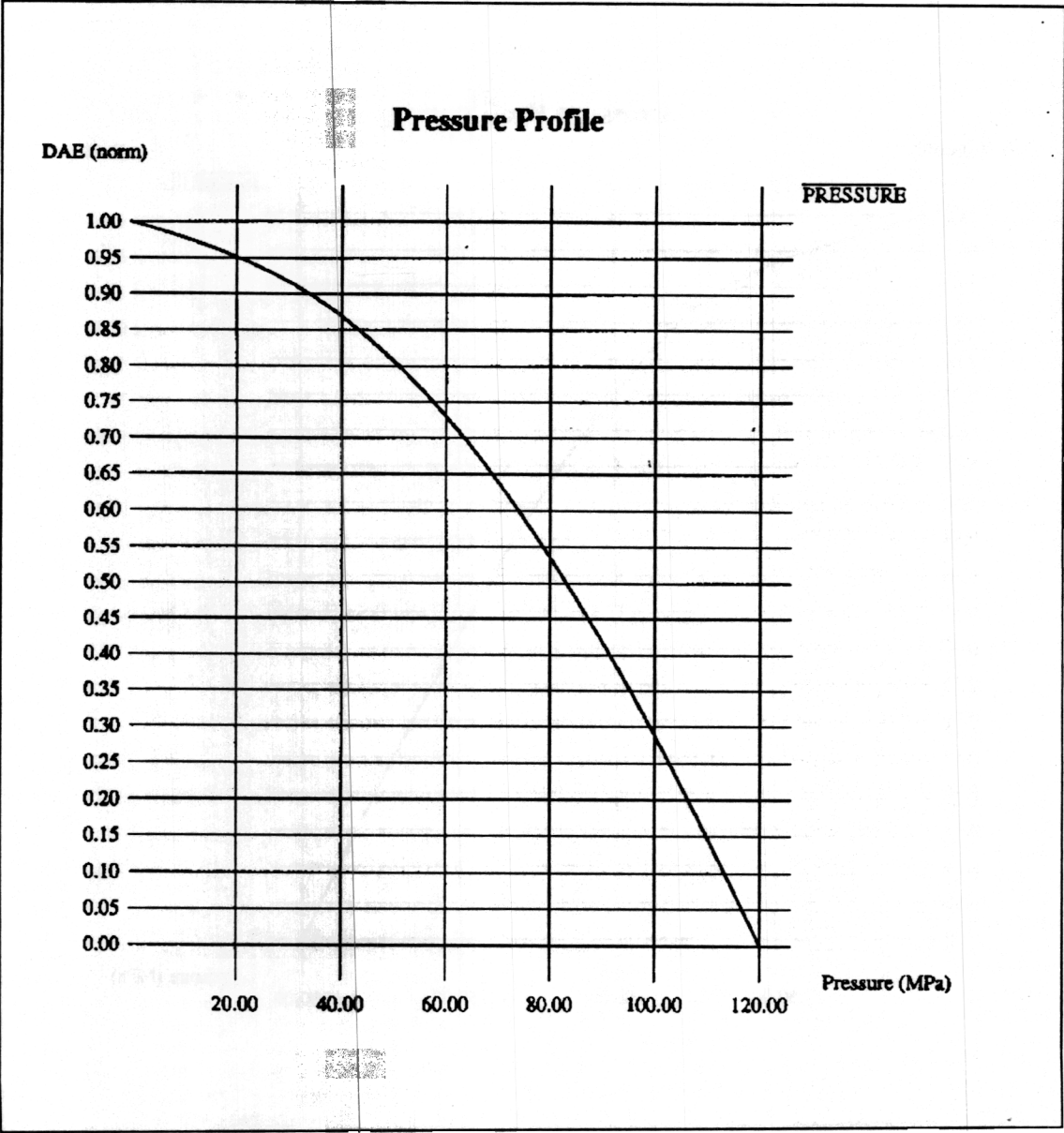


Figure 6 Pressure profile at 120 MPa

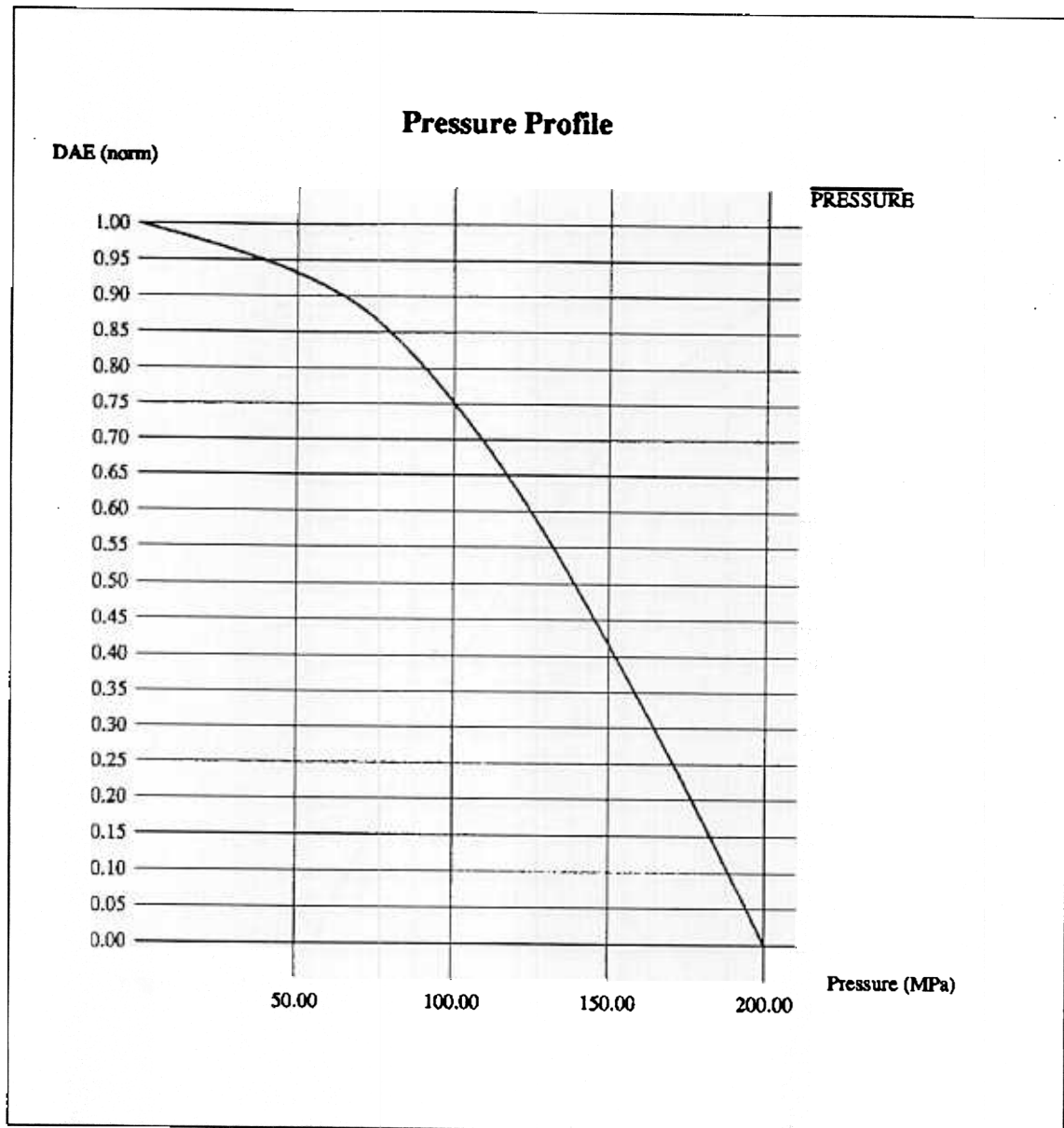


Figure 7 Pressure profile at 200 MPa