

Elastic Distortion Calculations at NPL on LNE 200 MPa Pressure Balances 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 two LNE 200 MPa piston cylinder units. 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,
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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 200 MPa unit belonging to LNE. 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 LNE. This report also includes results for a second and similar LNE 200 MPa unit. The units were number 5 and 4. 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 Samaan². The NPL results on the PTB unit were published in NPL report MOM117³.

2 DESCRIPTION OF THE LNE 200 MPa PRESSURE BALANCES

Both the LNE 200 MPa pressure balances are free deformation, simple design piston-cylinders and a sketch is shown in Figure 1. The units can operate in the controlled clearance mode but were not modelled in this mode at NPL.

The pistons and cylinders are made of tungsten carbide ($E = 6.3 \times 10^5$ and $\mu = 0.218$) and have a nominal effective area of 50 mm². From absolute diameter measurements the mean clearance in the working position is 0.25 μm for unit number 5 and 0.57 μm for unit number 4.

LNE ascribe a distortion coefficient of $\lambda = 0.85 \times 10^{-6} \text{ MPa}^{-1}$ to unit number 5 and $\lambda = 0.78 \times 10^{-6} \text{ MPa}^{-1}$ to unit number 4.

The pistons are at their working positions when the bottom point of each piston is 56 mm below the top surface of the cylinder. The piston-cylinder combinations have an engagement length of 40.6 mm.

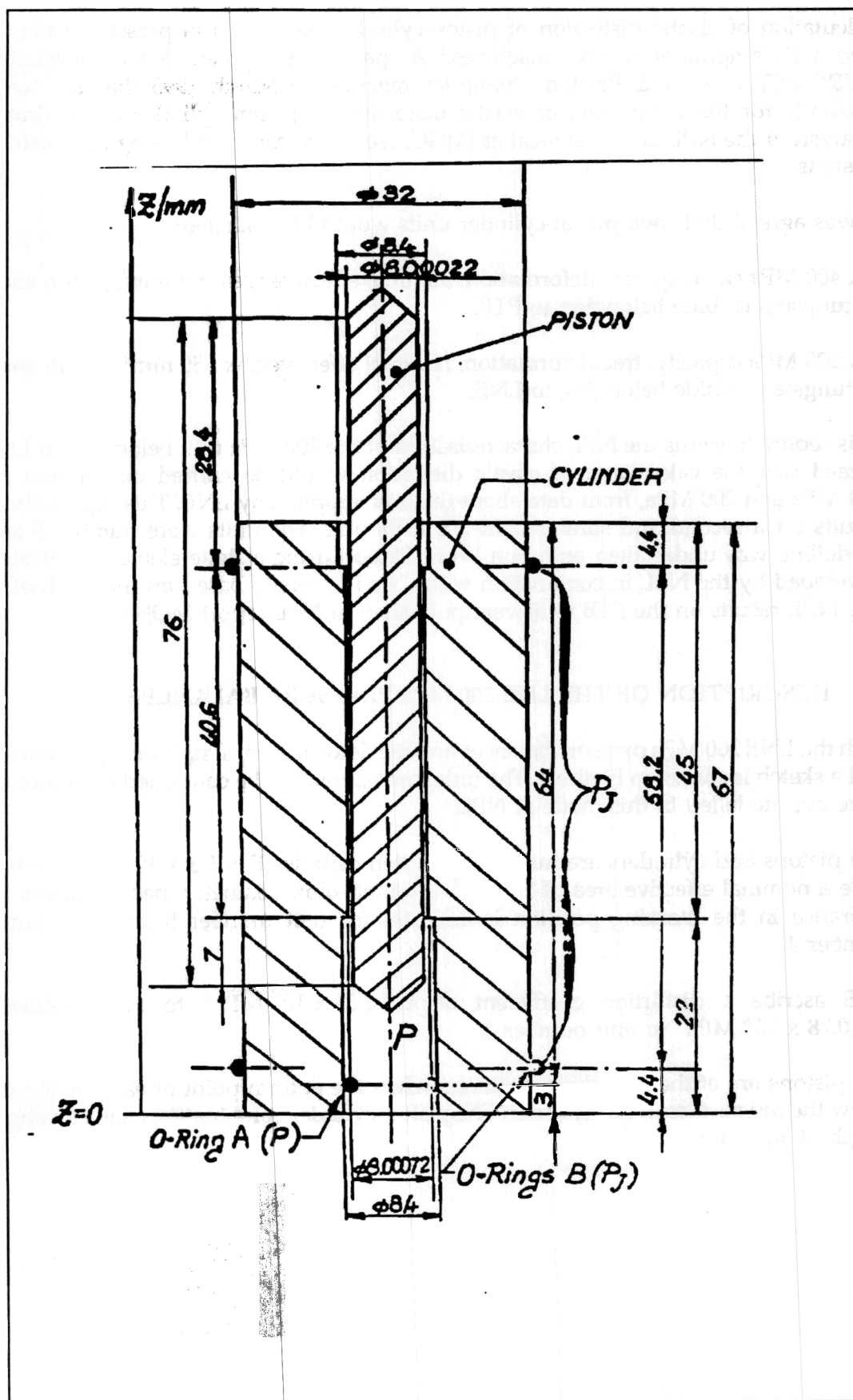


Figure 1 Piston-cylinder sketch (provided by IMGC from LNE)

3 MODELLING OF THE LNE 200 MPa PISTON-CYLINDER UNITS

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 2 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 the centre of the 'O'-ring at "HC" 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.

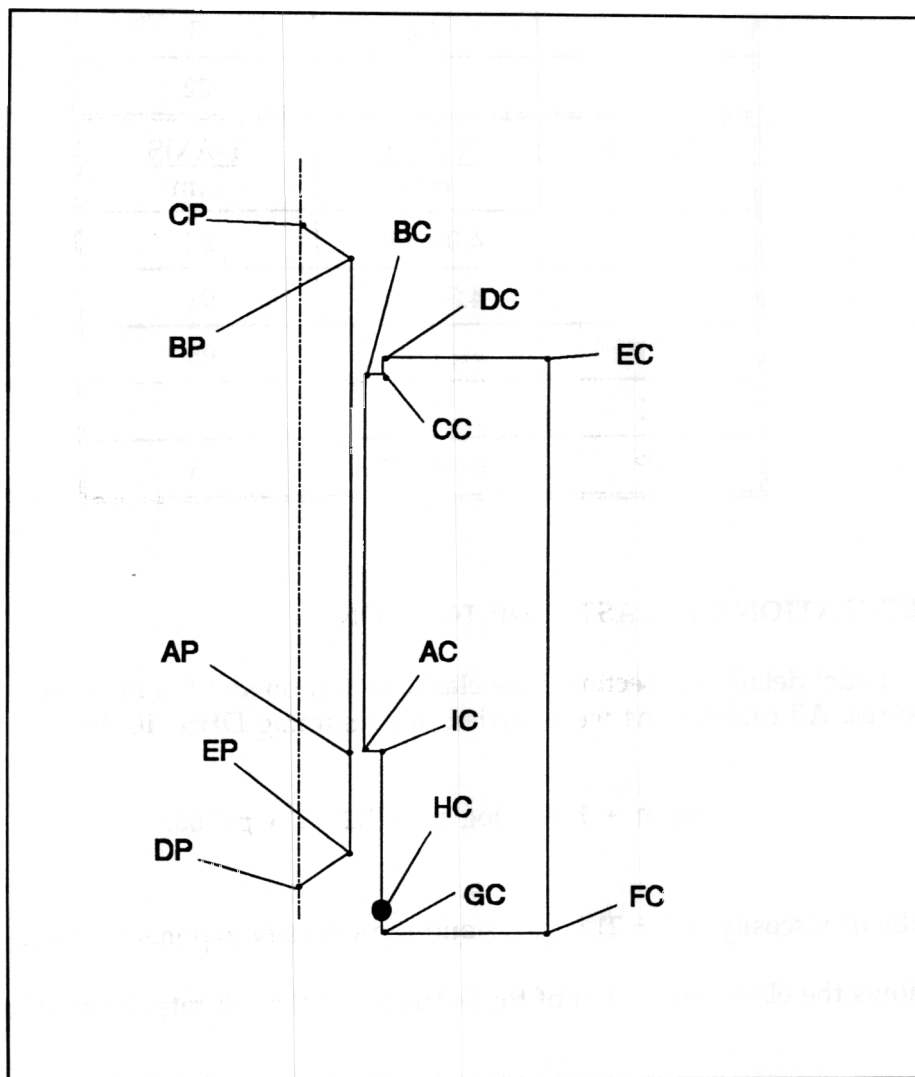


Figure 2 Piston-cylinder model

Table 1 Co-ordinates for piston-cylinder model (as provided by IMGC)

CYLINDER	<u>X-AXIS</u> mm	<u>Y-AXIS</u> mm
AC	4.000235	22
BC	4.000235	62.6
CC	4.2	62.6
DC	4.2	67
EC	16	67
FC	16	0
GC	4.2	0
HC	4.2	3
HC	4.2	22
PISTON	<u>X-AXIS</u> mm	<u>Y-AXIS</u> mm
AP	4.000235	22
BP	4.000235	91
CP	0	95
DP	0	11
EP	4.000235	15

4 CALCULATION OF ELASTIC DISTORTION

Using the model detailed in section 3 the elastic distortion and fall rates were calculated for two pressures. All calculations were carried out assuming DHS 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) = 21.5 mPa.s and the viscosity exponent (z) = 0.57.

Table 2 shows the elastic distortion of the balance and the fall rates calculated for DHS oil.

Table 2 Elastic distortion and fall-rate results

Unit 5 Initial gap 0.25 μm		
Pressure MPa	Distortion (λ) ppm/MPa	Fall rate mm/min
120	0.718	0.05
200	0.719	0.07
Unit 4 Initial gap 0.57 μm		
Pressure MPa	Distortion (λ) ppm/MPa	Fall rate mm/min
120	0.724	0.26
200	0.725	0.34

The radial clearance over the engagement length, for unit 5, was found to vary from 0.275 μm to 1.722 μm at 120 MPa and from 0.278 μm to 2.686 μm at 200 MPa. A graph of gap against displacement up the engagement length is shown in Figure 3 for 120 MPa and Figure 4 for 200 MPa.

The pressure profile in the engagement length is shown in Figure 5 for 120 MPa and Figure 6 for 200 MPa. Figures 3 to 6 can be found at the end of this report. "DAE(Norm)" is the normalised distance along the engagement length.

5 CONCLUSIONS

Using the data provided, the λ values for this piston-cylinder calculated using finite-element-analysis were found to be, for unit 5, 0.718 ppm/MPa at 120 MPa and 0.719 ppm/MPa at 200 MPa and for unit 4, 0.724 ppm/MPa at 120 MPa and 0.725 ppm/MPa at 200 MPa.

7 REFERENCES

- 1 Agreed EUROMET Project 256, Coordinator GF Molinar, IMGC, 29 March 1993
- 2 Samaan, N.D. *Mathematical modelling of instruments for pressure measurement*, PhD Thesis, City University, London 1990.
- 3 Clow, P. *Elastic Distortion Calculations at NPL on a PTB 400 MPa Pressure Balance as part of EUROMET Project 256*, NPL Report MOM117, July 1994.

8 PRESSURE AND GAP PROFILES

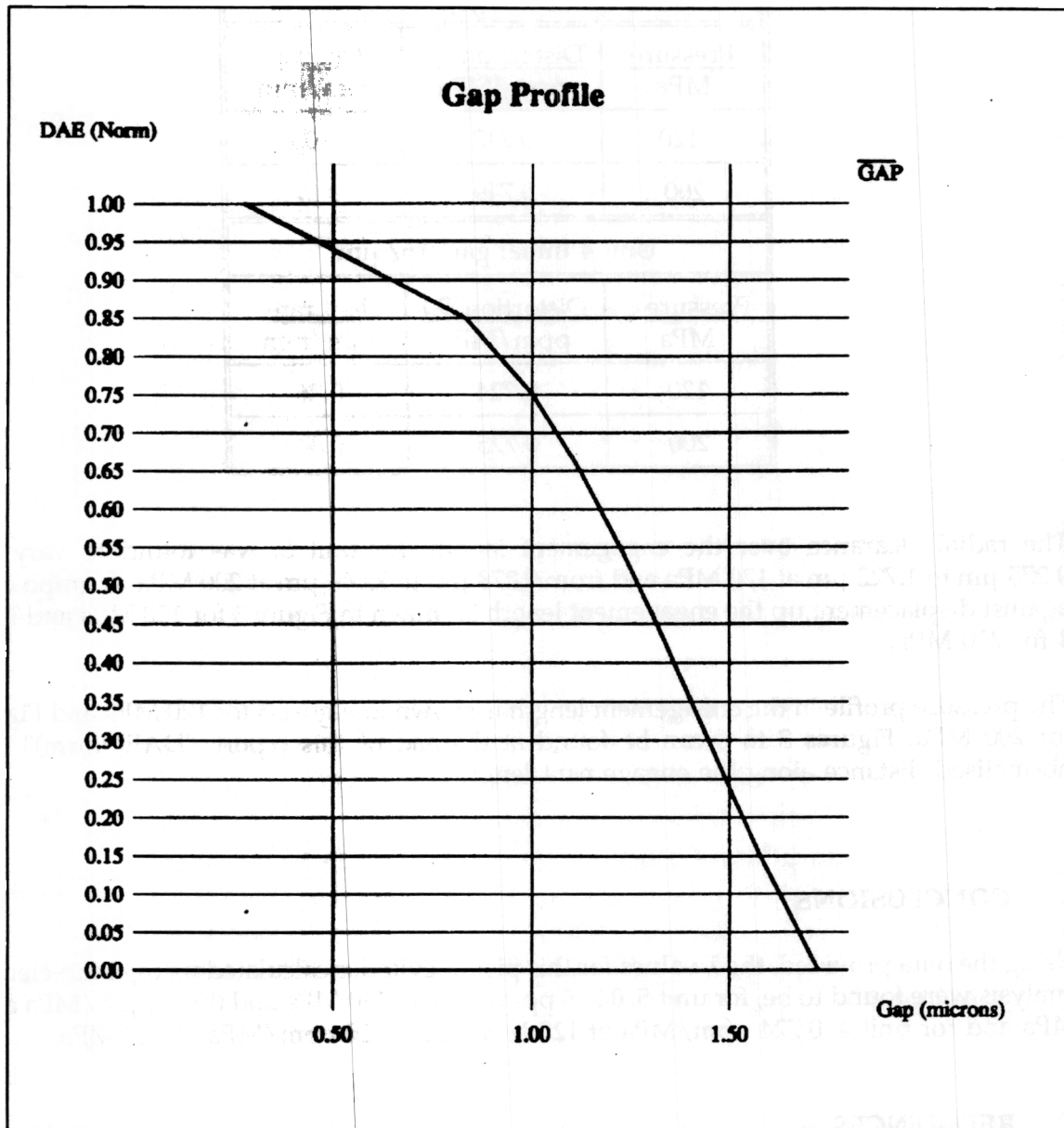


Figure 3 Gap profile at 120 MPa for unit 5

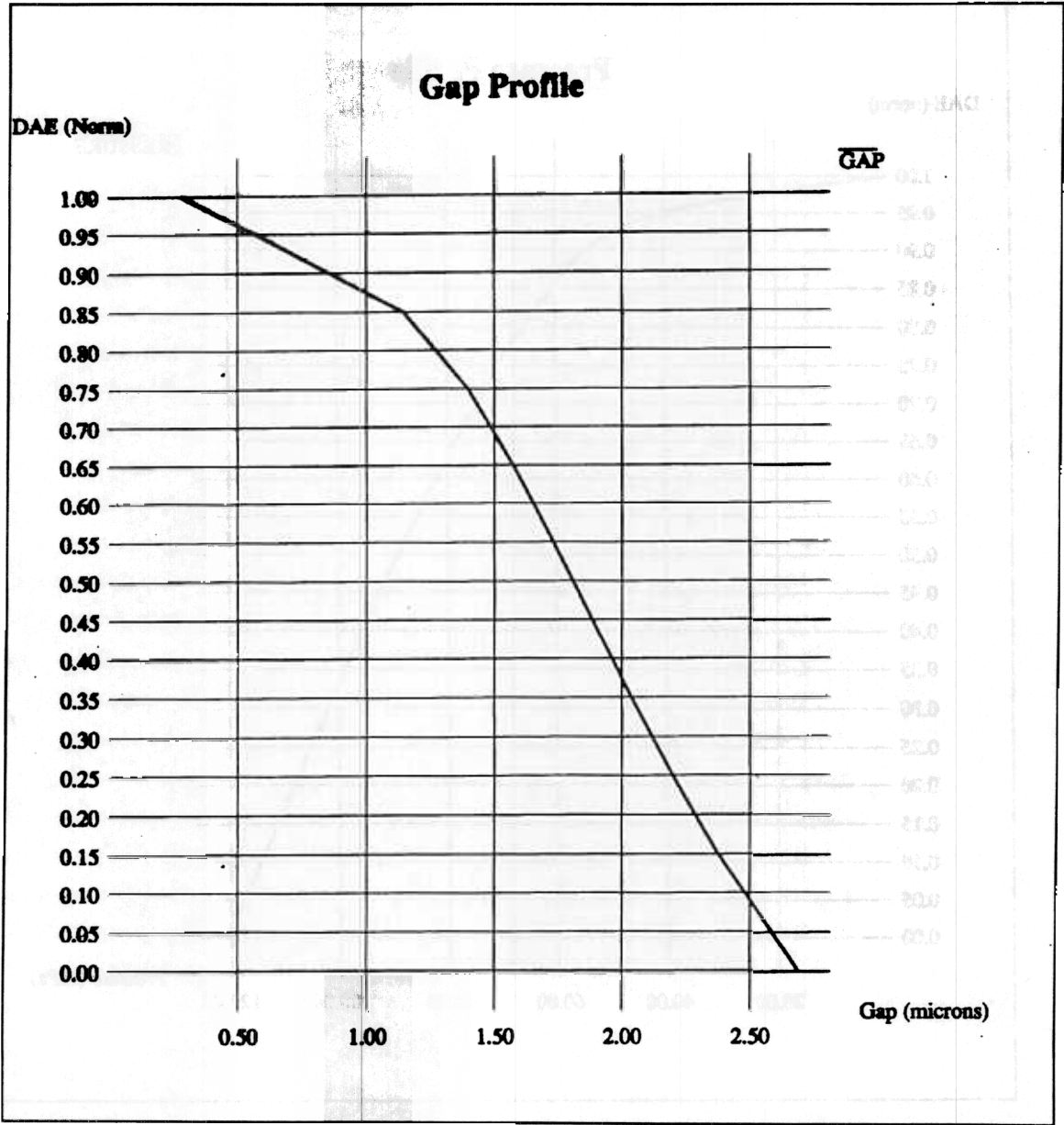


Figure 4 Gap profile at 200 MPa for unit 5

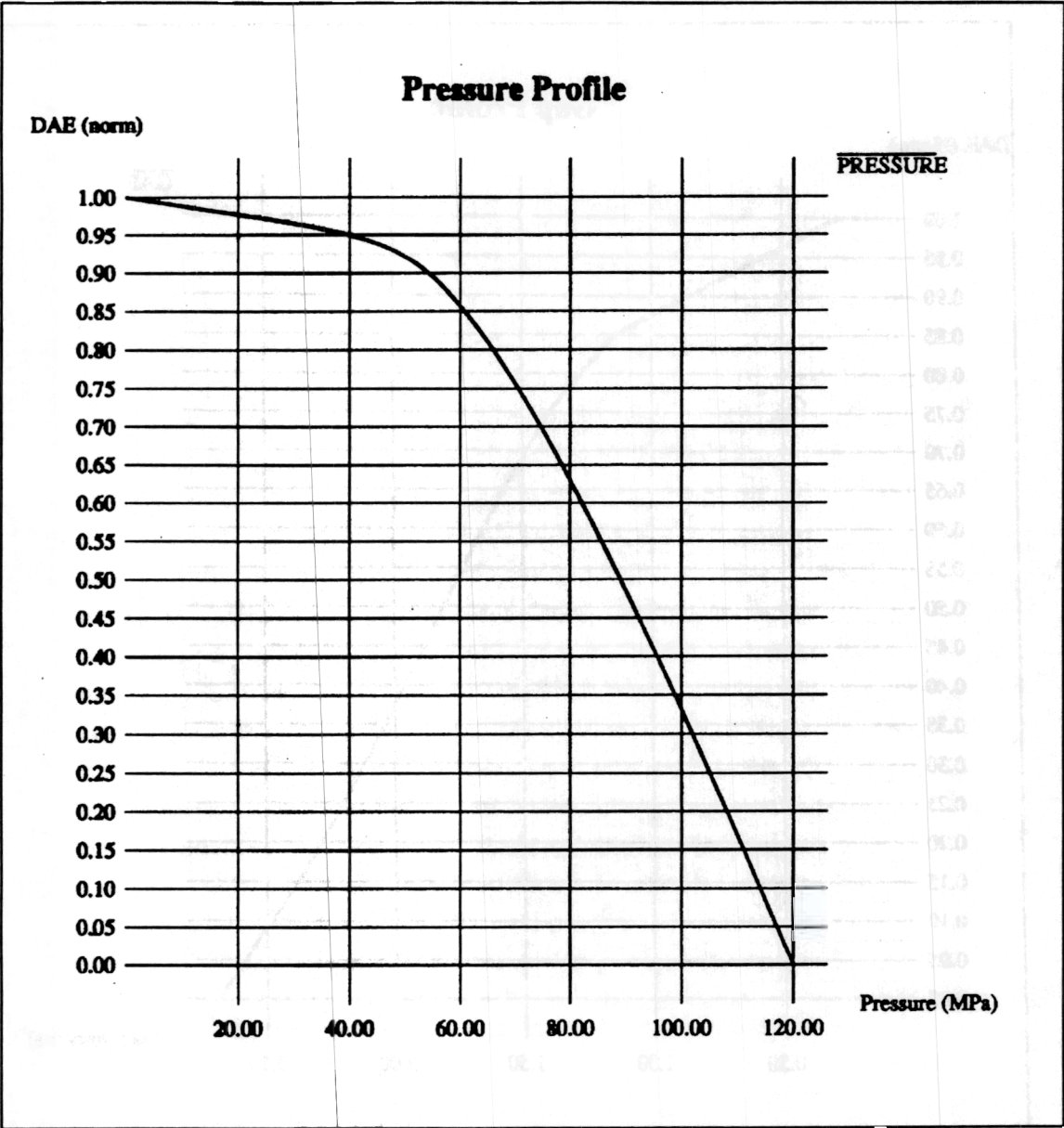


Figure 5 Pressure profile at 120 MPa for unit 5

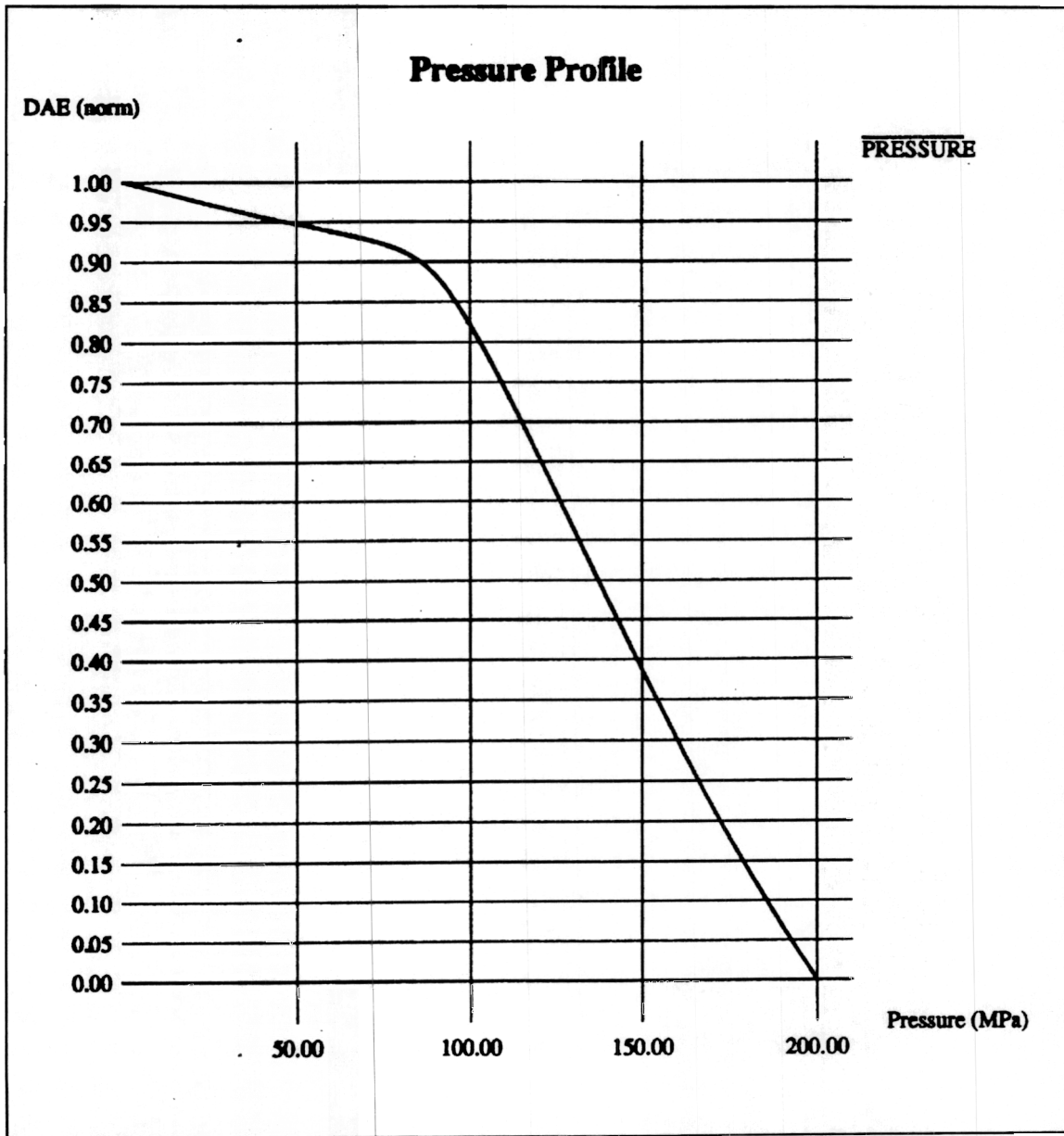


Figure 6 Pressure profile at 200 MPa for unit 5