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CALCULATION OF EFFECTIVE AREA BASED ON DIMENSIONAL MEASUREMENT FOR 35 MM DIAMETER PISTON-CYLINDER UNIT OF KIM-LIPI PRESSURE STANDARD

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Abstract – The calculation of KIM-LIPI 35 mm diameter piston-cylinder effective area, based on the dimensional measurement has been done successfully. This effective area was calculated by using simplified formula and simple numerical analysis. The purpose is to get a smaller uncertainty as the source of traceability chain for pressure in KIM-LIPI. The both result shows good agreement and only differ 0.6×10^{-6} relatively and it is consistence compare with the result based on crossfloat with relatively less than 2×10^{-6}.

Keywords: effective area, pressure balance, dimensional measurement, simplified formula, numerical analysis

1. INTRODUCTION

As in line with the development of CMC line as well as standard recalibration needs, independent traceability chain are getting important to NMIs for efficient cost and effort.

In the field of pressure, a reliable traceability chain requires one well-characterized reference piston-cylinder unit (PCU) of pressure balance. The effective area of the PCU will be used as the source of traceability and transferred to another pressure standard in another pressure range by direct comparison method, to establish the independent traceability chain. Considering the propagation of uncertainty, the reference PCU must have the smallest uncertainty. The calculation of PCU effective area with large nominal diameter, based on dimensional measurement has been proven to provide a smaller uncertainty, compare with direct comparison based on using cross float.

In this paper, the effective area A_0 of 35 mm diameter KIM-LIPI primary pressure balance PCU will be calculated by using dimensional data provided by PTB-Germany. The calculation will be rely on the simplified formula considering the simplicity, but another calculation of A_0 using simple numerical analysis will be conduct to investigate the consistency. Both result then to be validated against A_0 from calibration result based on crossfloat to investigate the agreement.

The calculated effective area of this PCU will be used as the source of traceability to establish the reliable traceability chain from low range pressure until high range pressure and also from pneumatic pressure to hydraulic pressure at KIM-LIPI.

2. CALCULATION OF P/C EFFECTIVE AREA USING DIMENSIONAL METHOD

Having the experiences in doing analysis of distortion coefficient PCU in high pressure (up to 1 GPa) by using Finite Element Method (FEM), supported by Ansys Parametric Design Language (APDL) program [1], KIM-LIPI also have done the preliminary study of the 32 mm diameter PCU effective area calculation based from dimensional measurement and also FEM [2], as shown in Fig. 1.

At the present KIM-LIPI is performing a study on calculating the effective area of primary PCU that has diameter of 35 mm. This 35 mm's PCU dimensional data measurement was obtained from Length laboratory of PTB Germany, while the previous dimensional data measurement of the 32 mm's PCU was done by Length laboratory of KIM-LIPI.

The basic different from the earlier study is, the number of data point. In first case, the dimensional data of PCU was very limited, only around 14 point along piston and cylinder gap. Moreover the PCU was considerably round and its surface straightness was also not considered in the calculation. FEM was used to estimate additional data point and to observe the distribution of the pressure along piston-cylinder gap.

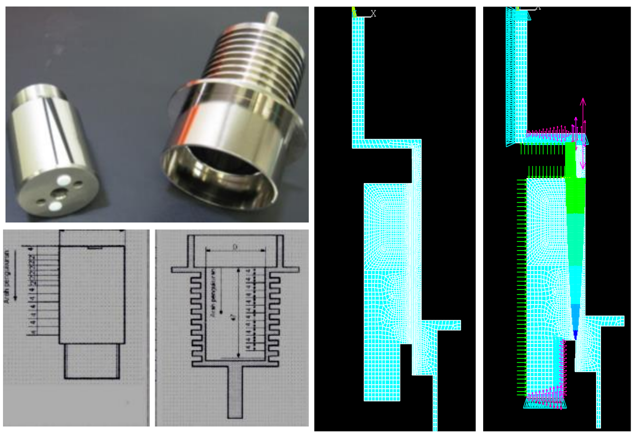


Fig. 1. A preliminary study of the calculation of effective area on 32 mm diameter PCU.

Fig. 2 shows the primary PCU of KIM-LIPI with the nominal diameter of 35 mm, which was sent to PTB Germany for dimensional calibration. The certificate provide sufficient data that are diameters, roundness, straightness and parallelism of both piston and cylinder.

Fig. 2. The 35 mm's diameter of KIM-LIPI primary PCU.

Three measurement axial position in direction of 0° – 180° and 90° – 270°, resulting 12 data of diameter on both piston and cylinder surface, as shown in table 1.

Table 1. Diameter of piston and cylinder provided by PTB Germany

Measurement position / mm	Piston Diameter / mm	
	0° – 180°	90° – 270°
14	35.332 25	35.332 32
0	35.332 47	35.332 51
-14	35.332 20	35.332 30
Measurement position / mm	**Cylinder Diameter / mm**	
	0° – 180°	90° – 270°
9	35.333 80	35.333 81
0	35.333 60	35.333 63
-9	35.333 80	35.333 82

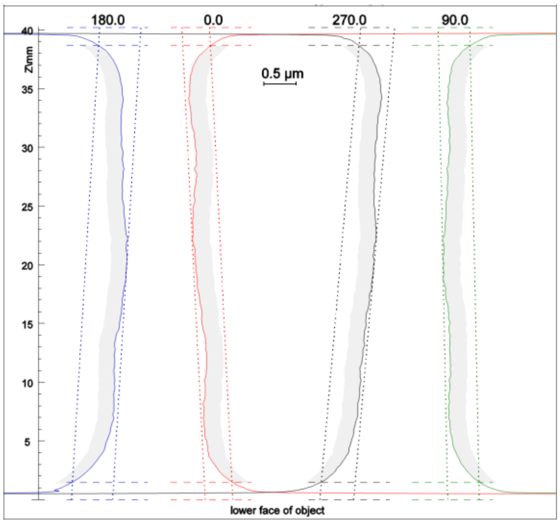


Fig. 3. The straightness and parallelism of PCU.

Since the straightness of piston and cylinder, as in Fig. 3, has also provided, therefore, the diameter of the PCU profile, suppose in the direction of 0° – 180°, can be estimated using a simple equation (1) as follow:

$$D_{(0^\circ-180^\circ)z} = D_i + \lfloor S_{0^\circ(z)} + S_{180^\circ(z)} \rfloor - \lfloor S_{0^\circ(D_i)} + S_{180^\circ(D_i)} \rfloor \qquad (1)$$

With $D_{0^o\text{-}180^o(z)}$ is an estimated diameter of piston or cylinder in *z* axial position in the direction of *0° – 180°*, correspond to the straightness data $S_{0^o(z)}$ and $S_{180^o(z)}$, with respect to straightness data $S_{0^o(Di)}$ and $S_{180^o(Di)}$ at selected reference diameter D_i , as shown in Figure 4.

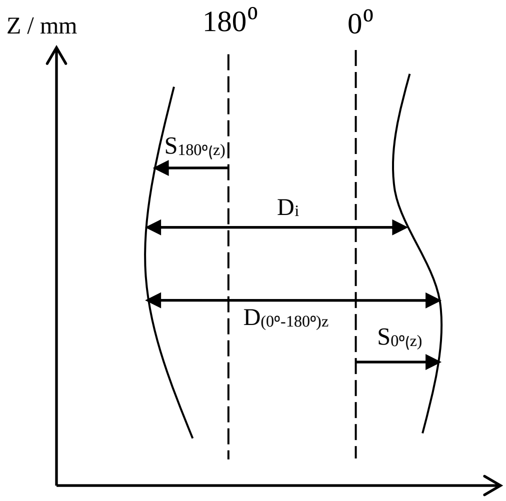


Fig. 4. Estimated diameter of piston or cylinder calculation in *z* axial position in the direction of *0° – 180°*.

Approximately 3000 and 2000 estimated data of diameter for piston and cylinder, respectively, with an interval 20µm, can be obtained by mean of equation (1).

The calculation of effective area were done on the basis of well describe equation in [3][4][5][6]. First, this simplified formula (2), was used to calculate the effective area (A_0) of the PCU,

$$A_0 = \pi\left(\langle d_p\rangle^2 + \langle d_c\rangle^2\right)/8 \qquad (2)$$

With d_p and d_c is the average of 6 diameter data of the piston and the cylinder in both the direction of *0° – 180°* and *90° – 270°*, respectively.

While for the calculation of effective area by numerical analysis utilizing a simple trapezoidal method, was done in accordance with equation 3, as follow:

$$A_0 = \pi r_0 \left[-r_0 + \frac{\int_0^l \frac{(r+R)}{(R-r)^3} dz}{\int_0^l \frac{1}{(R-r)^3} dz} \right] \qquad (3)$$

With r_0 is the piston radius at *z* axial position equal to zero (*z* = 0), *r* and *R* are the piston and cylinder radii at *z* axial position in the direction of *0° – 180°* and *90° – 270°*, from previous estimated diameter with respect to the 6 selected reference diameters.

The simplified formula (2) was selected for preliminary study considering the simplicity of the method, while the effective area in zero pressure A_0 (3) that can be solved using a simple numerical analysis, was selected to complement and to evaluate the discrepancies between them. The A_0 from extrapolation of several effective areas at certain pressure A_p by mean of FEM will be investigated latter.

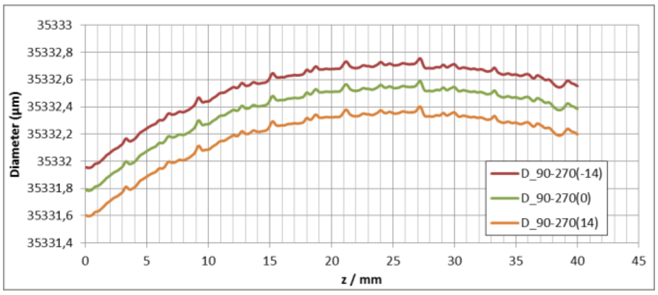
The uncertainty component to take into account in this works were; 1. Diameter of both piston and cylinder as the type B, 2. discrepancies of the diameter due to straightness, 3. discrepancies of the diameter due to roundness, 4. Simplification formula and 5. standard deviation of the average diameter from both piston and cylinder.

The calculated effective areas of PCU from two above approach method are compared with the calibration result based on crossfloat to evaluate the consistency.

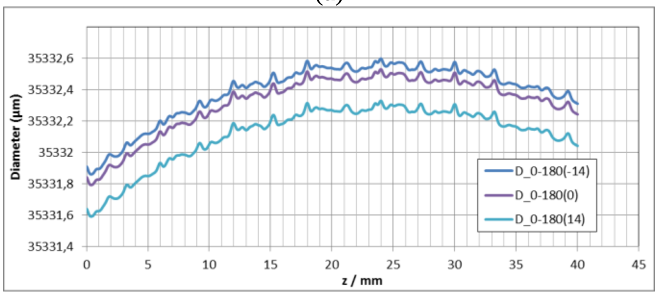
3. RESULT AND DISCUSSIONS

Using the simplified formula, obtained that the primary PCU of KIM-LIPI has effective area 9.805983 × 10^2 mm^2, with the typical relative expanded uncertainty 12 × 10^{-6}, assuming the expanded uncertainty of average diameter is 200 nm. This typical uncertainty is consistent with current study that result relative standard uncertainty 6.1 × 10^{-6} as shown with table 2.

As shown in Fig. 5, the PCU profile diameter of the piston that were estimated using equation (1), based on straightness data with respect to the reported diameter, differs when using different selected reference diameter. This discrepancies were taken into account as one of the component of uncertainty.



(a)



(b)

Fig. 4. Discrepancies of estimated diameter along the profile of the piston by using different reference diameter in both direction of 0° – 180° and 90° – 270°.

Using the simple numerical analysis, the calculated effective area A_0 obtained was 9.805104 × 10^2 mm^2, with the relative standard uncertainty 5.6 × 10^{-6}. The relative difference between both results were 0.6 × 10^{-6} and differs by less than 2 × 10^{-6} compared with the calibration result based on crossfloat, which is 9.805090 × 10^2 mm^2, with the relative expanded uncertainty 14 × 10^{-6}.

Table 2 described the evaluation of uncertainty that considering some necessary component.

Table 2. Uncertainty component of simplified formula calculation

Component	u (k=1) × 10^{-6}
u(D_p) from type A and type B	1.7
u(D_c) from type A and type B	1.7
Discrepancies of straightness	5
Discrepancies of roundness	2
Formula simplification	1.5
Total	6.1

Type B uncertainty for both piston and cylinder diameter were came from calibration certificate, while type A was the result of several point diameter standard deviation provided by the certificate due to simplification calculation of A_0. The discrepancy of the diameter due to straightness was contributed the biggest uncertainty in this study.

The uncertainty of A_0 that implement simple numerical analysis using trapezoidal rule as the advantages of the dense of dimensional data, does not considered the type A of both $u(D_p)$ and $u(D_c)$ component and the formula simplification component, therefore smaller uncertainty can be claimed.

4. CONCLUSIONS

It can be concluded that the calculation of effective area based on the dimensional measurement on the primary PCU with nominal diameter 35 mm belong to KIM-LIPI has been done successfully. However, the calculation of A_0 base on extrapolation from several A_p that more complex due to the utilization of FEM should also be evaluated to strengthen the result. The future works has been planned are to disseminate primary PCU to another PCU of pressure balance, including to link the oil to gas pressure balance, to establish a reliable traceability chain for pressure in KIM-LIPI.

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