Some advance in the study of the deformation of the piston-cylinder unit of a pressure balance using FE models

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Abstract: Previous works carried out by us were concerned by the development of axisymmetric Finite Elements (FE) in order to model metrological pressure balance. In this paper, a given pressure balance is studied. The very question is to verify if the analytical formulae, commonly used to deduce the pressure, are accurate. In particular, in the analytical approach, the piston-cylinder deformation is taking into account by the use of a global distortion coefficient obtained by tests. This approach is compared to FE calculations where local deformations are naturally considered. For the pressure balance under study, and for the model used, the relative error obtained when comparing the FE effective area and the analytical effective area is of 0.1 per cent.

Keywords: Finite Element, OpenCavok, pressure balance, VEB Gertewerk.

1. INTRODUCTION

For the pressure balance under study, the measured pressure is obtained from the analysis of the different components of the forces applied to the system. The pressure balance operates with liquid and the measured pressure *p* is finally given by the analytical formula of equation 1.

$$p = \frac{\left[m_p\left(1-\frac{\rho_a}{\rho_{mp}}\right)+\sum m\left(1-\frac{\rho_a}{\rho_m}\right)\right]\cdot g_l+\sigma C}{A_{0,\theta}\left[1+\left(\alpha_c+\alpha_p\right)\cdot(\theta-20)\right]\cdot\left(1+\lambda p_n\right)} \pm \rho_{fluido}\, g_l \Delta h \qquad (1)$$

A full description of this formula can be found in [1] as well as comprehensive theory and practice concerning pressure balance in [2-5].

Our interest lies in the denominator of equation (1) where the effective area is expressed as,

$$A_{eff} = A_{(0,\theta)}(1+\lambda p_n) \qquad (2)$$

when, θ, the temperature of the piston at the time of the measurement is set to 20°C. The area of the piston-cylinder unit is expressed in m^2 and λ, the distortion coefficient of the piston-cylinder unit in p_n^{-1}.

In the coming sections the objective is to compare the formula (2) to FE calculations.

2. ANALYTICAL STANDARD APPROACH

To use the formula (2), the parameters $A_{(0,\theta)}$ and λ are evaluated from calibration tests.

Five calibration tests were carried out over the past 25 years for the pressure balance under study, a VEB Gertewerk oil-operated pressure balance. The pressure balance operates in the nominal range of [5; 50] MPa. The hydraulic fluid is a Tellus VG 32 oil. Figure 1, shows the piston of the pressure balance.

Figure 1. Piston unit.

Figure 2 is a view of the piston-cylinder unit

Figure 2. Piston-cylinder unit.

3. NUMERICAL APPROACH

The FE model consists of the piston and of the cylinder which is around the piston. Several positions, called engagement length, are considered. In the cavity above the piston, hydrostatic fluid elements are used. A thin slice of fluid is also considered at the piston-cylinder interface. Other FE-based model can be constructed such as in [6] where the solid parts are modeled using FEs while an analytical formula is used for the fluid pressure model.

Figure 3 shows the FE model developed. The axis of symmetry is necessary the x axis in our numerical code. Therefore, the piston-cylinder is turned clockwise of 90 degrees. The pressure is input at the left side. The model consists in 280,000 finite elements. OpenCavok FE code [1,7] developed at our laboratory is used. The model is parametrized, the applied pressure and the engagement length of the piston can be changed.

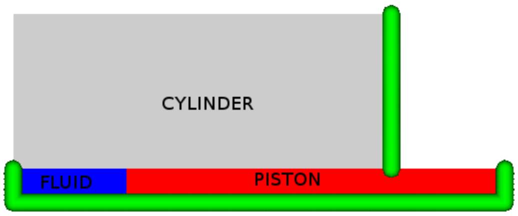

Figure 3. Piston-cylinder unit Axisymmetric FE model.

The fluid cavity and the fluid gap between the cylinder and the piston are modeled using an hydrostatic fluid. Figure 4 shows the FE mesh at the piston-cylinder interface.

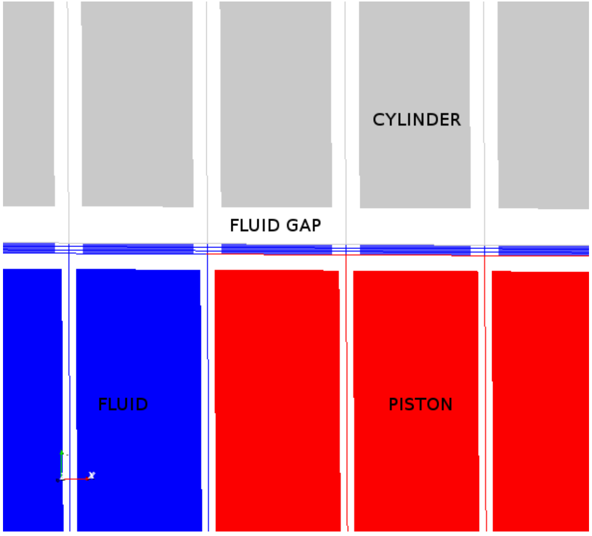

Figure 4. Piston-cylinder mesh interface.

Figure 5 is an illustration of typical FE outputs.

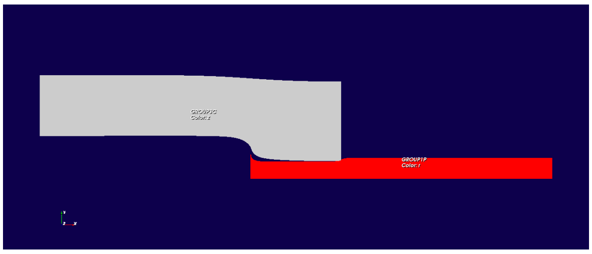

Figure 5. Amplified radial deformation of the piston(red) – cylinder(grey) unit.

4. RESULTS AND DISCUSSION

In fact, two FE models are considered. It allows us to have an idea of the sensibility of the calculation regarding some sizing parameters.

Model 1, length = 20 mm, Piston diameter = 3,561 mm, Cylinder external diameter = 20 mm, clearance with the piston of 0.003mm (φ cyl − φ piston).

Model 2, length = 47 mm, Piston diameter = 3.561 mm, Cylinder external diameter = 29.9 mm, clearance with the piston of 0.003mm (φ cyl − φ piston).

The main difference between the two models is that the model 1 is shorter than model 2.

4.1. Effective areas as a function of the applied pressure.

For a given engagement length of 30%, is explored the evolution of the effective area for different values of the applied pressure. The pressure balance operates in the pressure nominal range of [5; 50] MPa. Results are presented in Fig. 6 and 7, respectively for model 1 and 2. What is noticeable is that the FE curves are linear as the analytical ones. Calculations are extended to zero pressure to verify the convergence of the curves at this point.

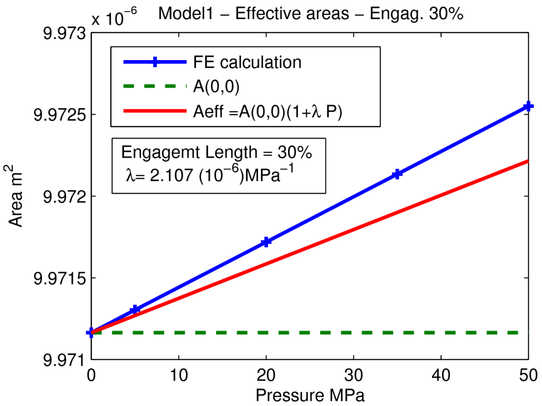

Figure 6. Model 1 - Effective area and pressure.

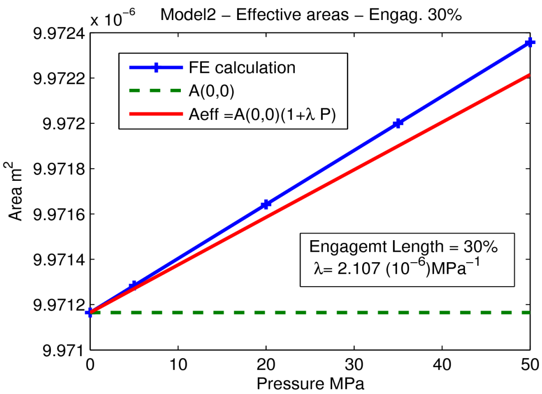

Figure 7. Model 2 - Effective area and pressure.

The two models exhibit the same trend. If we believe the FE models, it indicates that the analytical λ parameter is lightly underestimated by the calibration tests.

4.2. Effective areas as a function of the engagement length

Another way to analyze the results is to fix the pressure and investigate several positions of the piston.

Figures 8 and 9 are showing the results respectively for the first and second model. As long as the piston reaches the top position (0 engagement length), the FE calculus differ from the A_{eff} analytical results. The overestimated value at 0% of engagement length is not of very interest for us. What is under our interest is the 10% to 90% operational engagement length.

It is clear also that the analytical formula do not account for the engagement length, which is why A_{eff} is constant.

For those interested by the best engagement position, this position is found to be 100%, which is not a realistic position in operation. The following approach based on an analytical adjustment valid in all the [10, 90%] is therefore preferred.

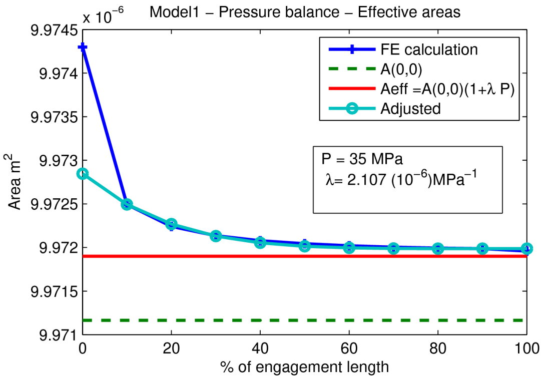

Figure 8. Model 1 - Effective area and engagement.

An adjustment of the analytical formula is suggested by the mean of a simple function. An x^2 function centred at 100% engagement could be imagined. However, an $a(90\text{-}x)^5+b$ function, which flatten the curve, is chosen, a e b being identified using the computed FE values at 10% and 90% of engagement length.

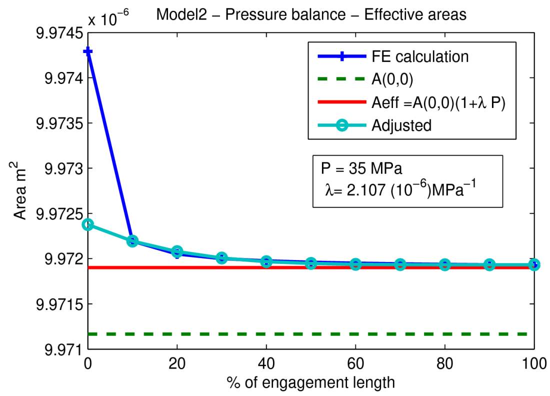

Figure 9. Model 2 - Effective area and engagement.

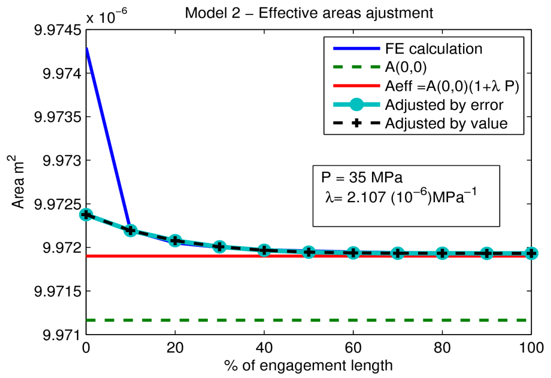

Figure 10. Model 2 – Adjustment of the analytical formula.

More interesting is the adjustment proposed in figure 10, called adjustment by errors. This adjustment is based on the calculus of relative errors. The graphics of errors could be established once for a given pressure balance and kept as a corrective technical form.

4.3. Effective areas relative error

Figure 11 is a graph where the relative error of the FE models is compared to the analytic solution. It shows that the difference between the FE models (which account for local deformation) and the analytical formula (which used a global distortion parameter) is less than 0.1%.

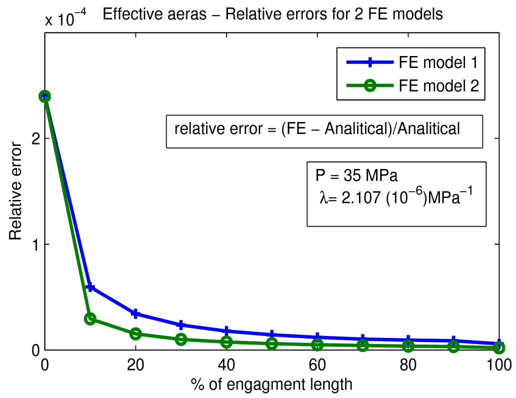

Figure 11. Relative error FE/Analytical for the two FE models.

We may recall that this relative error is concerned by the calculation of the effective area which is only one term of the analytical formula that gives the measured pressure.

4.4. Other results

The FE model 1 and model 2 are quite similar, the main difference is the length of the piston which is respectively of 0.02 m and 0.047m. The model 2 conforms to the dimensions of the true pressure balance.

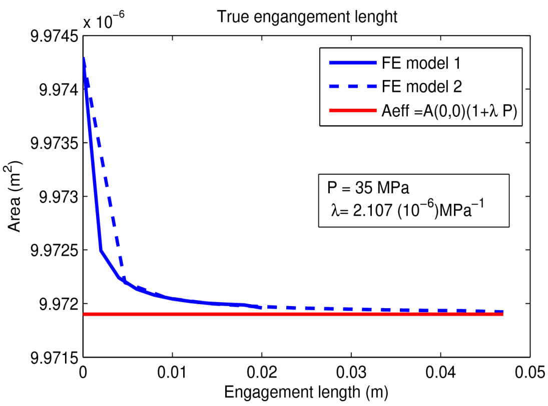

Figure 12. Comparison of model 1 and 2 using the true engagement length.

Figure 12 indicates that better results should be expected with a long piston pressure balance than a short piston pressure balance.

Even if not interested by the 0 to 10% engagement length from an operational point of view, complementary calculations were carried out. In the basic analyses presented previously, computational points where only spaced every 10%.

Figure 13 presents the convergence to zero. From 0 to 10%, calculations are carried out every 1%.

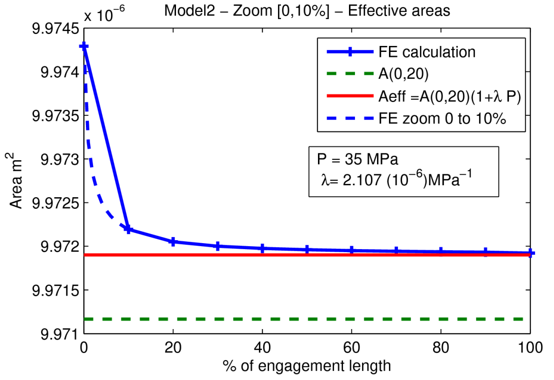

Figure 13. Convergence to zero.

More than physical results, it indicates for us that, if interested by limit values, the numerical geometric models, truncated at their effective parts in this study, should be modified and extended to the true geometry.

5. CONCLUSION

FE models were developed in order to study the influence of local deformation on the effective area of the piston. For our pressure balance and our models, the relative error on the calculation of the effective area of the piston is found to be 0.1%. For the operational range [10%, 90%] of engagement, a corrective x^5 function is proposed for the matching of the analytical and FE curves.

The FE models have helped us in the understanding of our pressure balance. As we find a small divergence of 0.1%, it validates the value of the λ parameter which is obtained by calibration tests. For coming studies FE models should be used to compare pressure balance based on different principles.

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REFERENCES

[1] Soares Júnior L, da Silva Júnior F I and Lamary P 2015. A theoretical and experimental study of the deformation of the piston-cylinder unit of a metrological pressure balance, Journal of Physics: Conference Series 648 (2015) 012020, doi:10.1088/1742-6596/648/1/012020

[2] Dadson R S, Lewis S L and Peggs G N 1982 The Pressure Balance: Theory and Practice (London: H.M.S.O.)

[3] Dadson R S, Lewis S L and Peggs G N 2011 Calibration of Pressure Balances (EURAMET cg-3)

[4] Lewis S L and Peggs G N 1992 The Pressure Balance: A Practical Guide to Its Use (London: H.M.S.O.)

[5] Kobata T 2011 Multiple cross-float system for calibrating pressure balances Proc. of the 5th CCM and 4th IMEKO TC16 (Berlin)

[6] Yagmura L and Bagli E F 2009 Experimental and dimensional characterization of a prototype piston-cylinder unit and validation using finite element analysis (FEA) Measurement B 42 678-684

[7] Lamary P, de Araujo Bezerra R, da Silva Junior F I, Pontes de Deus E and Benallal A 2014 A multi-physic implementation of the finite element method apllied to research on acoustic poro-elastic materials Proc. Of the CILAMCE (Fortaleza) DOI: 10.13140/2.1.3301.6644