

Deformed gap space using macro-micro FEA model and transferred into a CFD model

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Using a cylindrical nozzle and seat of a Pressure Relief Valve (PRV) the surface form and waviness is modelled using actual metrological data i.e. average surface form and waviness (W_a and W_{sm}) in a $\frac{1}{4}$ symmetry manner. To model the surface waviness the technique used is based on the summing technique created by Tsukizoe & Hisakado [1, 2] for micro contact analysis. Due to the actual surface form measurements being in the micro-meter range, the model is required to incorporate micro and macro-meter dimensions. The material in question is stainless steel. The deformed finite element analysis model is then transferred into a CAD geometry allowing the void space to be meshed and solved using computational fluid dynamics.

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This paper will first focus on how metal-to-metal contacting surfaces are modelled and deformed (based on measured surface average form and waviness) using Finite Element Analysis (FEA) within ANSYS[®] Workbench 16.1. Secondly, the method used to retrieve the gap space between the deformed surfaces, allowing it to be transferred into a Computational Fluid Solver (CFD) solver is described. The fundamental structural FEA assumptions will also be discussed briefly. The metal-to-metal contacting surfaces in this study are of a Pressure Relief Valve (PRV). To understand the basic components of a PRV, metrological measurements (i.e. average surface form, waviness and roughness) and some further literature please refer to [3]. This study is part of a research program to investigate and model leak tightness of a PRV.

The main purpose of a PRV is to relieve a pressurised system by expelling excess gas/liquid at a specific set pressure. As the operating pressure within a PRV reaches the set pressure, the sensitivity of the valve opening prior to reaching an equilibrium position (i.e. opening pressure = set pressure) increases. Consequently, for metal-to-metal contacting surfaces, the leakage of the gas/liquid also increases, making it more challenging to seal the valve above 90% of the set pressure (i.e. opening pressure). Thus, mitigating or reducing leakage is advantageous to industry. The metal-to-metal contacting surfaces are called the seat and disc where the latter is connected to a spring which provides the required force up to the set pressure point.

Using the Alicona Infintefocus (a confocal and variable focus metrology measurement instrument), the average surface form and waviness of the whole seat and disc was measured. It was found that the average surface form of both the disc and seat followed a $\frac{1}{4}$ symmetric shape with a deviation of about $5 \mu\text{m}$ and $2.1 \mu\text{m}$ respectively. The average form follows a sinusoidal shape which is due to the finishing technique used by the sponsor. The surface waviness of both the seat and disc was measured and combined using the summing technique (created by Tsukizoe & Hisakado [1, 2]) being $W_a = 312 \text{ nm}$ and $W_{sm} = 2.35 \text{ mm}$. The summing technique is a method of combining surface finish conditions of two contacting surfaces into a single surface in contact with a flat rigid surface. See Figure 1a and 1b.

Taking into consideration the surface form shape ($\frac{1}{4}$ symmetric) and deviation, waviness parameters and the summing technique, the valve seat is modelled in Computer Aided Design (CAD) and the contacting face is modelled using the combined metrological measurements using simplistic surface geometries in the shape of pyramids (see 1c). Also (following the summing technique) the disc is modelled as a rigid idealistic flat surface. The seat is made of AISI 316(L) steel, while the disc is a much harder material with a yield stress roughly 3 times greater than AISI 316(L) steel. To account for the elastic material response of both materials, the Young's modulus is calculated using a "joint modulus" (E^*) which is based on Ohm's law of resistance with respect to Poission's ratio of both materials:

$$\frac{1}{E^*} = \frac{1 - \nu_1^2}{E_1} + \frac{1 - \nu_2^2}{E_2}, \quad (1)$$

where E^* and $E_{1 \text{ or } 2}$ – joint modulus and Young's modulus of material 1 or 2, and $\nu_{1 \text{ or } 2}$ – Poisson's ratio of material 1 or 2 correspondingly. The major assumption here is that the material at this scale is still governed by constitutive mechanics rather than specific polycrystalline relations. Future work may focus on accounting for polycrystalline in the form of tessellations using custom APDL scripts within ANSYS.

Using ANSYS Workbench 16.1 the $\frac{1}{4}$ symmetric CAD models of the flat rigid surface and the seat are brought into contact and deformed in an elastic-perfectly plastic manner. A fixed boundary condition is placed on the bottom of the seat while symmetry is applied either side of the seat to impersonate a whole seat and disc in contact. The rigid flat disc is rotationally fixed as well.

The deformed gap space between the contacting surfaces in the FEA solver must be transferred (1-way) into a CFD solver. The method to undertake the 1-way transfer would follow the flowchart presented in Figure 2. Once the model is deformed,

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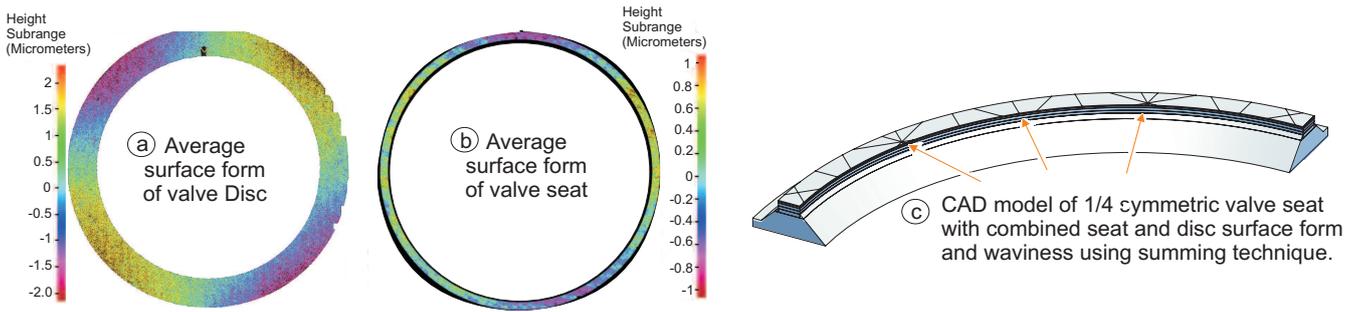


Fig. 1: Alicona infinite focus used to measure average surface form and waviness of (a) disc and (b) seat and then combined (using summing technique) into a (c) $\frac{1}{4}$ symmetric CAD model created in SolidWorks

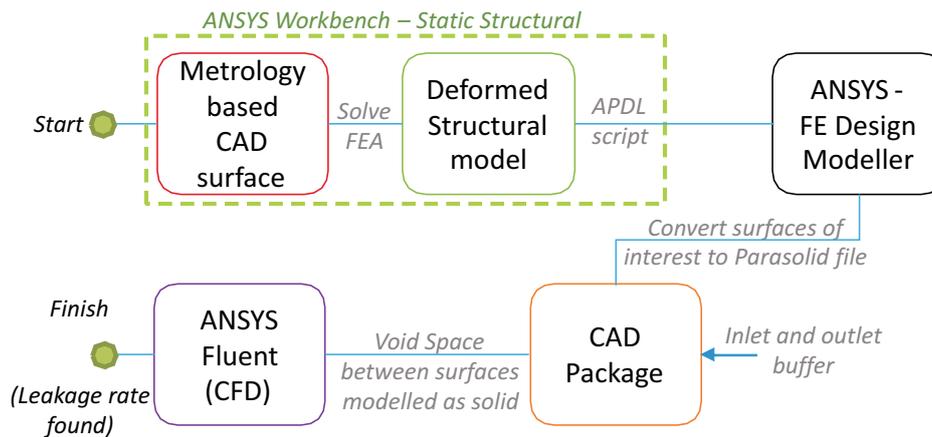


Fig. 2: 1-way SFI method to measure valve leakage using ANSYS Workbench 16.1 and standalone CAD package

the original geometry mesh is updated to the deformed configuration using the “UPGEOM” command [4] and subsequently saved as the native ANSYS “*.cdb” file type. This “cdb” file type is accessed via the “Finite Element Modeller” package in ANSYS Workbench allowing one to be able to save the contacting surfaces as a Parasolid file type (*.x_t). The contacting surfaces can then be modified by adding inlet and outlet buffer zones ready to be meshed for a CFD solver.

ANSYS does have the capability to undertake 1-way and 2-way Fluid-Structure Interactions (FSI), however this method is a 1-way Structure-Fluid Interaction (SFI). A 2-way FSI could be utilized, however the issue that arises is that once the contacting surfaces become closed in certain regions, the CFD meshing capabilities in ANSYS fails as it does not recreate the original CAD model to account for closed contacting elements.

For this particular project air has been chosen as the fluid type. The gas of air is presumed to be ideal and pressurised at 18.6 MPa at the inlet assuming flow in a laminar fashion and adiabatic. Due to the mean free path and length of the channel, the fluid is found to be in the slip flow regime. Therefore, it must account for Maxwell’s boundary slip condition at the walls. The gap space must be meshed appropriately across the wall to account for the slip conditions. For further information on CFD validation please refer to reference [5].

In conclusion it has been shown that it is possible to create a 1-way SFI. The technique presented is not automated, however, it does lend itself well for this particular research program since the pressure of the fluid is not high enough to cause any structural deformation. Also such a model in a 2-way FSI would be very expensive since the meshing capabilities required for the micro-nanometre range are high. Future work will focus on validating results from simulation of the CFD model by comparing with experimental results.

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