Validation of Electromagnetic Load Simulations for Fusion by Digital Image Correlation (DIC)

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Abstract. Fusion machines that are based on magnetic confinement of plasma present an extreme electromagnetic (EM) environment causing body forces to components of potentially several MN. These EM loads will be a design limiting constraint for fusion components. It is therefore crucial to validate EM simulations against data-rich experiments. To date, these validation efforts have been lacking well-characterized fusion-specific experiments. Image-based diagnostics such as DIC facilitate accurate and precise measurement of deflections, in this case caused by EM forces. In this work, we will present an EM validation experiment aimed at measuring deflections of thin pure copper plate caused by the Lorentz EM force using DIC. To this end, we built an EM experimental set-up using a 3-axis Helmholtz coil system to create controlled magnetic fields combined with controlled current running through the thin copper plate. Data we gathered from this experiment is used to create an image-based validation framework for EM simulations.

Introduction

In the recent years, the use of DIC has extended from focusing on materials behaviour characterisation and properties identification to be included in the validation and qualification process of materials and components in different industries, see [1], [2] and [3] among others. Validation requires the quantification of experimental uncertainties of the whole DIC measurement chain. In this work, we aim to apply the same procedure to an EM validation experiment. The experiment exploits the Lorentz EM force to create deflections in a thin copper plate supplied with a controlled electrical current. Preliminary results show an acceptable level of agreement between simulation and experimental results, though the full quantitative comparison has not yet been analysed.

Experiment

Fig. 1 shows the experimental set-up. It is composed of the 3-axis Helmholtz coil (Schwarzbeck HHS 3D 5213-50) and 300x10 mm pure copper plate with 0.127 mm thickness. Both were controlled by two separate digital bench power supplies (Rohde & Schwarz HMP4030). We used a stereo-DIC set up and an IR camera to monitor sample temperature during the test. We used cameras with almost 2:1 ratio between the horizontal and vertical resolutions (4,096x2,160 pixels) for efficient use of pixels given the sample shape. As the main quantity that we are interested in is the deflection out of plane, we designed the set up to have a wide stereo angle (~30°). We have also used an NI-9205 data acquisition card to record voltages running through the sample and the coil.

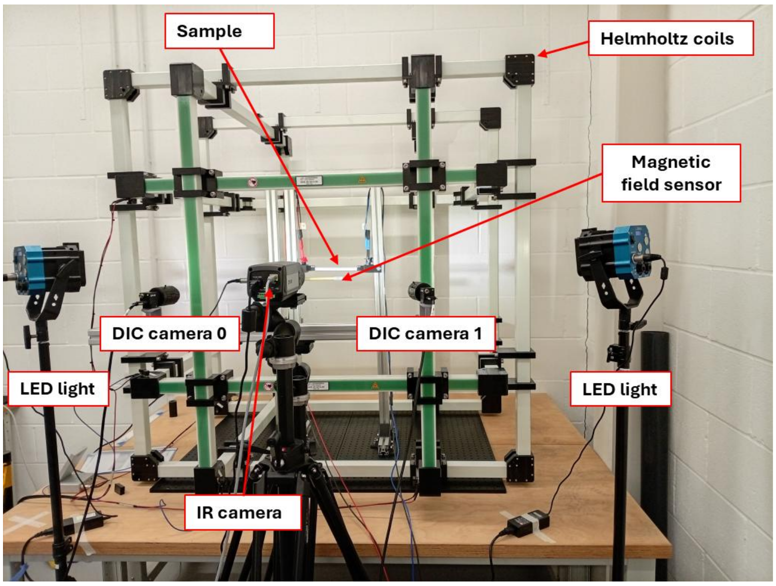

Figure 1: Experimental set up

Results

The preliminary results of Fig. 2.a) show the temporal noise floor maps for the displacement fields of the sample obtained from a set of 50 static images before introducing the current into the coils or the sample. The reference image that we considered is the average of another 50 static images taken in the same conditions. The missing data in the right side of the sample is due to poor speckle quality. The values are less than 2 μm for most of the sample for the in-plane component of the displacement and under 4 μm for the out of plane component. Fig.2.b) shows the average displacement maps under steady state conditions i.e. after few seconds of applying the current to both coil and sample. The maximum deflection is measured in the central area of the sample as expected. The values are approximately 70 μm in this area. We have yet to perform a quantitative comparison to fully assess the validity of these FE models, though preliminary analysis indicates that the measured deflection values are comparable to the simulation results, which suggests that a useful validation can be performed in due course.

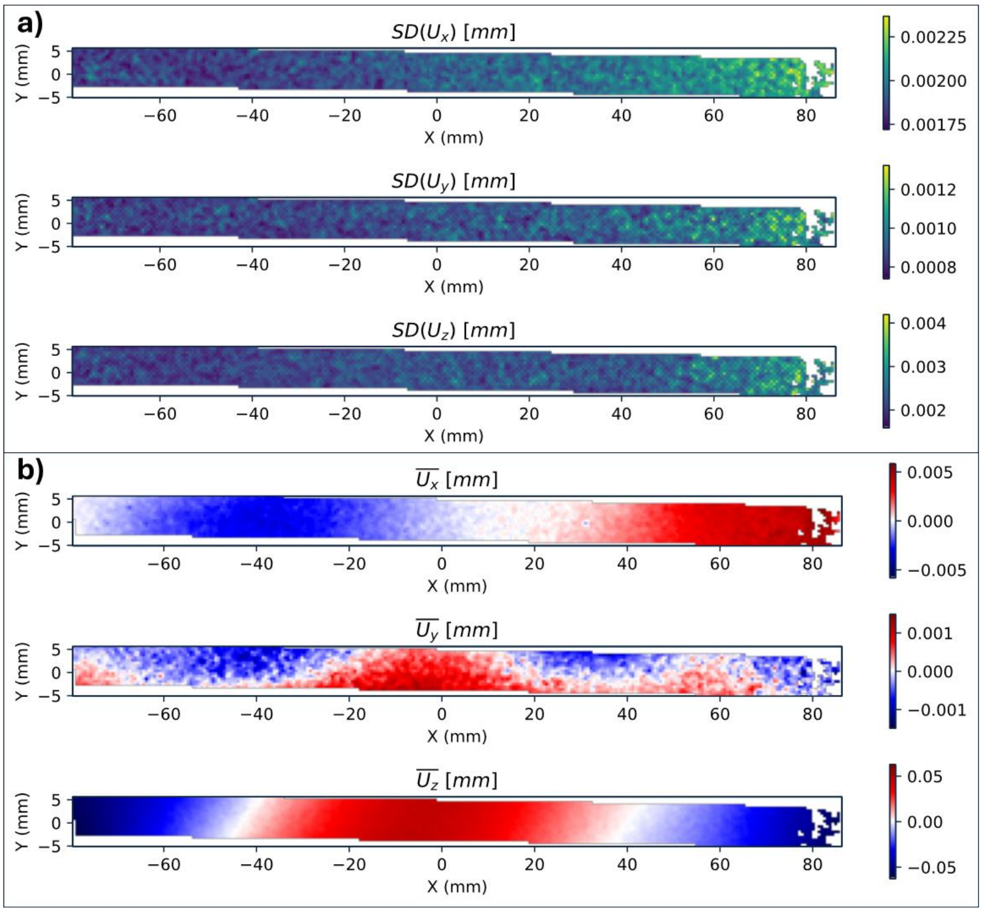

Figure 2: Preliminary experimental results: a) Temporal noise floor and b) average displacement at steady state

Conclusion

In this work, we designed an EM validation experiment using image-based diagnostics. The preliminary results show that wide stereo angle in the stereo DIC setup gave the out of plane resolution needed for our tests. In the future, we will use this data to validate EM simulations taking into account experimental and simulation uncertainties with appropriate validation metrics.

References

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