Les Rencontres Scientifiques de l'IFP – LES for Internal Combustion Engine Flows - 18-19 November 2010

Characterisation of cyclic variability in an optically accessible IC Engine by means of phase-independent POD

Benjamin Böhm[1], Francesca di Mare[2*], Andreas Dreizler[1]
1 TU-Darmstadt, Center for Smart Interfaces, Darmstadt, Germany,e-mail : dreizler@csi.tu-darmstadt.de
2 DLR, Institut für Antriebstechnik, Köln, Germany,e-mail: francesca.dimare@dlr.de
** Corresponding author*

Abstract — Characterisation of cyclic variability in an optically accessible IC Engine by means of phase-independent POD — *Investigation of cyclic variability in engine operation has recently received new impulse with the widespread application of advanced numerical and experimental techniques. The present work attempts to shed some light on the existence and nature of correlations between coherent structures dynamics and cyclic variability in IC engines by means of phase-independent Proper Orthogonal Decomposition applied to highly-resolved PIV measurements obtained in an optically accessible, motored engine. Analysis of the conditional means and variances of the reconstruction coefficients reveal interesting patterns in the break-up of coherent structures which are also confirmed by experimental observation and leave room for speculation on the true nature of the flow field at different crank angles. A first attempt has also been carried out to reconstruct missing information from available measurements, with encouraging results: the development of such interpolation/reconstruction technique could obviously have a great impact on the reduction of the cost normally involved in experimental and computational campaigns.*

INTRODUCTION

The variability and unpredictability of operation conditions is the subject of a large number of investigations, in particular in an attempt to identify and characterize the events leading to abnormal behaviours and hence attain a better control of pollutant emissions.

Proper orthogonal decomposition has gained increasing popularity in both experimental and numerical studies of the flow in IC engines thanks to its ease of implementation and to the wealth of information that it can provide. Fogleman et al. [1] and Roudnitzky et al. [2] have employed POD to characterize the coherent and fluctuating components of the velocity field in motored IC engines without combustion. Bizon et al. [3] applied POD to the luminosity field in a fired, optically accessible engine to investigate cyclic variability.

In the present work, the use of POD, both as analysis and prediction tool is illustrated. Two-dimensional velocity measurement in a motored, optically accessible engine have been employed to study the statistical characteristics of the POD modes and reconstruction coefficients. Finally, a quadratic interpolation technique has been employed to reconstruct data between available measurements.

1 EXPERIMENTAL AND NUMERICAL SETUP

Flow field measurements were performed using high speed particle image velocimetry (PIV). The one cylinder, spray-guided, spark-ignited, direct injection engine with a bore of 82 mm and a compression ratio of 9.6 had four valves and a pent roof. Charge motion was controlled by varying the cross section of the horizontally aligned twin inlet manifold. The engine was motored at 1000 rpm. Two components of the flow field were captured in a plane at 6 kHz, resolving 1 CAD at 1000 rpm [4].

Phase-Independent Proper Orthogonal Decomposition of the two-component vector field has been carried out following the snapshot method proposed by Sirovich [5], using a total of 5840 discrete samples (snapshots). For the phase-independent POD, the PIV data were interpolated on a fixed cartesian mesh accounting for 1892nodes, taking care to preserve the indivergence of the velocity field. The eigenvector problem has been solved using a direct, divide-and-conquer method. An iterative Arnoldi-Lanczos method [6-7] has been also adopted with almost identical results, The latter approach can be conveniently used for large systems where the traditional divide-and-conquer methods prove to be excessively slow.

RESULTS AND DISCUSSION

An interval of 5 degs CA has been chosen to sample the experimental data. Form the chosen sample, 1168 modes have been extracted, the first of which is represented in figure 1.

As the modes are only space-dependent, a correlation analysis can be carried out on the reconstruction coefficients, which represent the temporal evolution of the system and thus shed some light on the events that lead to cyclic variability. As only the compression stroke has been investigated, only the correlation of the strongest first modes in each cycle has been considered. The coefficients of mode 2 and 3 share similar trends, therefore only the correlation between a(t)[k=1] and a(t)[k=2] are shown in figure 2. It would appear that the break-up of the coherent tumble motion brought about by compression is indeed reflected in the loss of clustering of the values of the coefficients. It is important to note that the modes constitute an orthogonal basis and are hence decorrelated.

If the customary representation of the normed amplitudes of the reconstruction coefficients vs. angle for each cycle is adopted (fig. 3), it can be observed that for the first five modes, with exception of mode 1, an increase in variability exitsts after CA 40, again when the compression stroke destroys the coherence present in the first half of the cylinder run. Indeed smaller, turbulent structure are created. It also shown that hardly any influence of the sampling procedure can be detected. The amplitude of the coefficients associated with modes 3-5 is such that their influence on cyclic variability can not be deemed determinant. On the contrary, exceptional values observed within the first 40 degs. in strong components of the flow field can lead to the speculation that these are in fact responsible for cyclic variability. This hypothesis seems corroborated by the observation made during the experiments [4], where a few cycles displayed abnormal behavior with respect to the characteristics of the tumble motion. For one of these (cycle 51) it can be seen that the coefficients amplitudes for modes 1 and 2 lies outside the maximum error interval (fig. 4).

During the present study reconstruction of the full velocity field, starting from available information has been also attempted. The possibility of obtaining complete set of data could have a large impact on the reduction of the costs of experimental and numerical campaigns. A quadratic interpolation method has been adopted to obtain the reconstruction coefficient of all modes at two arbitrarily chosen points in time. The interpolated coefficients have been then employed to reconstruct the fluctuating velocity field (figures 5 and 6). A qualitative comparison between the reconstructed and measured field shows that the major features characterizing the structure of the flow are correctly captured. The L2 norm of the relative error was found in the worst case as high as 40%. This results was not entirely unexpected, but does not indicate that the flow field is structurally incorrectly predicted and further work is currently in progress to improve the reconstruction method.

2 CONCLUSIONS AND FUTURE WORK

In the present study, POD has been adopted to investigate cyclic variability in a motored, optically accessible engine. The analysis of the reconstruction coefficients shows that it is indeed possible to extract from the latter information, both quantitative and qualitative, on the nature of the flow. In particular, it appears that cyclic variability is determined by the (non-linear) interaction of the strongest coherent motions, rather than by the weaker, erratic “turbulent” components.

Previous studies have also shown that POD can be used to decompose the flow field in a coherent and Gaussian part [1], but in order to obtain a more accurate characterization of turbulence, more information should be extracted on the integral length scale: this could be achieved through analysis of the vorticity of the modes, that, although wave solutions of a dynamical system, are dimensionally velocities.

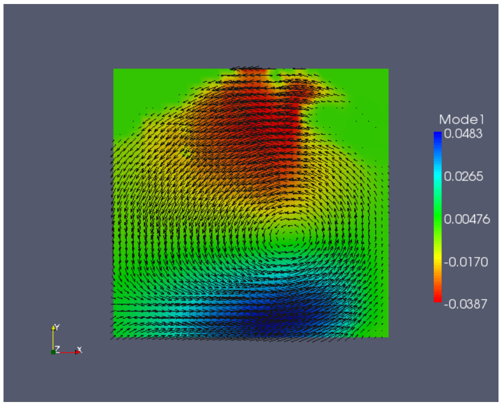

Figure 1 :

Mode 1: scalar field set as the x-component of the model.

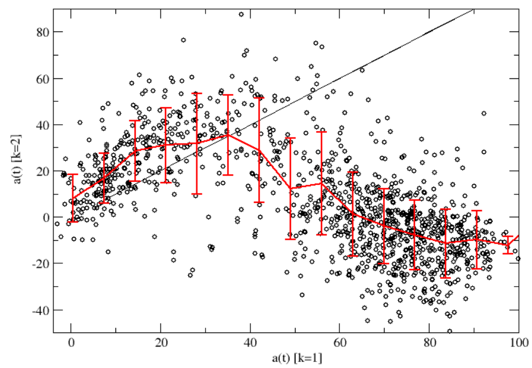

Figure 2:

Correlation between the reconstruction coefficients of modes 1-2 for all cycles.

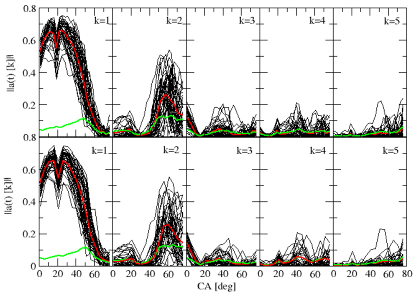

Figure 3 :

Normalised amplitudes of reconstruction coefficients Top: sampling every 3 degs. Bottom: sampling every 5 degs. Legend: black line: time-dependent amplitudes, cycles 1-73; red line: cycle-averaged amplitudes; green line: variance (cycle-based) of the amplitudes.

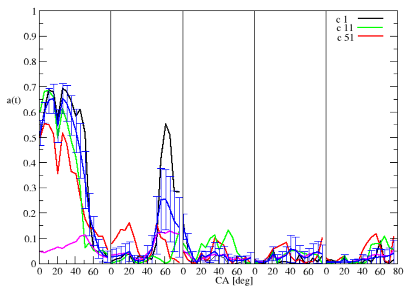

Figure 4 :

Abnormal behavior of cycle 51 evident from the cycle-based statisctics of the reconstruction coefficients. Legend: see graph for the amplitude curves. Magenta line: cycle-based variance of the amplitudes.

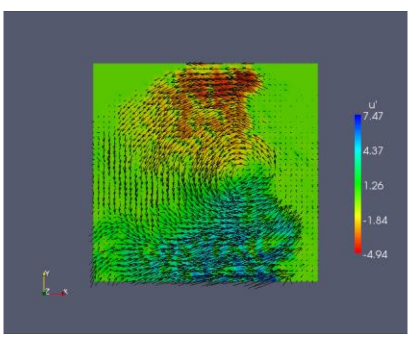

Figure 6:

Reconstructed velocity field (fluctuating) for cycle 7 at 53 degs CA

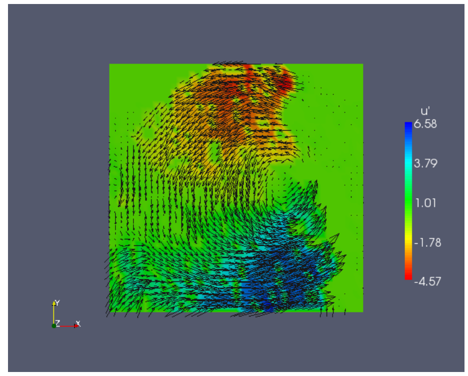

Figure 7 :

Measured velocity field (fluctuating) for cycle 7 at 53 degs CA.

ACKNOWLEDGMENTS

The present study was financially supported at TU-Darmstadt by EXC-259. F. di Mare wishes to thank Prof. R. Mönig and Dr. E. Kügeler at the Institute of Propulsion Technology, DLR-Köln, for their continued support during this work.

REFERENCES

1. S. Roudnitzky, P. Drouault and P. Guibert, *Journal of Turbulence*, (2006), 7:1-19
2. M. Fogleman, J. Lumley, D. Rempfer and D. Haworth, *Journal of Turbulence*, (2004), 5:2-17
3. K.Bizon, G. Continillo and B.M. Vaglieco, 30th Meeting on Combustion, Italian Section of the Combustion Institute
4. S.H.R. Müller, B. Böhm, M.Gleißner, R. Grzeszik, S. Arndt, A. Dreizler, *Experiments in Fluids*, (2010), 48:281-290
5. L. Sirovich, *Quart. J. Appl. Math.*, (1987), 45(3):561-590
6. http://www.netlib.org/lapack
7. http://www.caam.rice.edu/software/ARPAC