A comparison of classical and novel phase averaging technique for quasi-periodic flow

F. Cozzi, A. Coghe
Dip. di Energetica, Politecnico di Milano

XV Convegno Nazionale A.I.VE.LA.
Facoltà di Ingegneria Politecnico di Milano
29 - 30 novembre 2007
MOTIVATIONS

Classical phase average is commonly used to analyze quasi periodic flows, i.e. periodic Vortex shedding, Precessing Vortex Core ...

Disadvantages:
- require an external reference signal
- Increase time and costs of experimental activity

A novel phase average techniques has been developed (AIVELA 2006)

Advantages:
- Does not require an external reference signal
- Post processing technique

Performance of the new technique as compared to the classical procedure?

How much results are affected by characteristics of experimental LDV data (data rate, turbulence intensity ...) and by the value of parameters used in the data post processing
OBJECTIVE

- Assess reliability and applicability of the novel phase average technique to quasi periodic flows
  - Effect of: LDV data rate, turbulence level, parameters used in the post processing...
  - Apply classical and novel phase average techniques to the same LDV data set
    - Two test cases: swirl flows showing periodic velocity fluctuations
      (a) high amplitude (b) low amplitude
  - Compare and analyze results
UNSTEADY FLOWS

According to the decomposition proposed by Hussain e Reynolds the instantaneous local velocity can be divided into 3 components:

\[
\mathbf{u} = \bar{\mathbf{u}} + \left( \bar{\mathbf{u}} - \bar{\mathbf{u}} \right) + \mathbf{u}'
\]

Mean Velocity  Random fluctuation

Time varying mean velocity (periodic)

Phase average allows to separate periodic velocity fluctuation and random fluctuation
1) In the *classical approach* an external signal (i.e. pressure) is used to generate a time mark at a specific phase reference.

2) Velocity data are sorted according to the above time mark.

**HARDWARE PHASE AVERAGE**

C. E. Cala, E. C. Fernandes, M. V. Heitor, S. I. Shtork
Coherent structures in unsteady swirling jet flow
1) In the *novel approach* the time mark is generated from the velocity data itselfs.

2) Velocity data are sort according to the above time mark.

C. E. Cala, E. C. Fernandes, M. V. Heitor S. I. Shtork
Coherent structures in unsteady swirling jet flow
NOVEL PHASE AVERAGE
GENERATION OF TRIGGER SIGNAL

TRIGGER: TIME INSTANTS OF ZERO CROSS, $t_{0i}$.

- Re-sample LDV data
  - $f_{\text{resampl}} \gg f_p$
  - Nearest Neighbor Re-sampling

- Remove Mean

- Band pass Zero Phase Filter
  - Ideal Filter (FFT - FFT$^{-1}$)
  - Center Frequency = $f_p$
  - Filter Bandwidth = 20 Hz

- Identify time instant of zero cross, $t_{0i}$
EXPERIMENTAL SETUP 1

Free Swirling Jet

5W Ar Ion Laser

LDV Head

Bragg Cell + Fiber Output

Sync 1

BURST SPECTRUM ANALYZER

Reference trigger signal generated from a band-pass filtered Microphone signal
Experimental Setup 2

Confined Swirl Jet

Low PVC intensity

LDV Head

Bragg Cell + Fiber Output

5W Ar Ion Laser

Burst Spectrum Analyzer

Sync 1

Microph.

LDV Head

Axial and Tangential air flows

Microph. Voltage supply & Amplifier

BAND-PASS filter

Butterworth BP-filter

80 Hz bandwidth

-48 dB/octave

TTL generator

Trigger @ 0 Volt level

Negative slope

Photomultiplier

Reference trigger signal generated from a band-pass filtered Microphone signal
Original, filtered (80 Hz bandwidth) and TTL signals
EXPERIMENTAL RESULTS
FREE SWIRLING JET

Mean tangential velocity profile at nozzle exit
EXPERIMENTAL RESULTS
FREE SWIRLING JET

A peak (PVC) is clearly visible at 481 Hz

A very small amplitude 2nd harmonic is visible at 964 Hz

Resampling freq: 10kHz, original data rate ~4400 Hz

Re ~24400
r = 12 mm
EXPERIMENTAL RESULTS
FREE SWIRLING JET

Signal to Noise Ratio estimated from Hardware Phase Average results

\[ \text{SNR} = \frac{\text{RMS turbulent}}{\text{RMS periodic}} \]

For all data points SNR \( \sim 1 \)

\[ \text{RMS periodic} = \sqrt{\frac{1}{T} \int_{0}^{T} (\bar{u} - \bar{v})^2 \, dt} \]

\[ \text{RMS turbulent} = \sqrt{\frac{1}{T} \int_{0}^{T} (u - \bar{u})^2 \, dt} \]
Phase difference between hardware and software phase averages is due to the different trigger signals:

- **Hardware**: microphone signal (pressure) FBW 80 Hz
- **Software**: LDV data (velocity) FBW 80 Hz

Re ~24400
r = 12 mm
Once re-aligned, *hardware* phase average and *software* phase average are nearly identical.

The RMS value of periodic component is used to compare the two technique:

- \( \text{RMS}(\tilde{u})_H = 4.70 \text{ m/s} \)
- \( \text{RMS}(\tilde{u})_S = 4.98 \text{ m/s} \)

The difference is about 6%.
A 10% difference in the RMS values corresponds to a rather small local differences
- A 10% difference in the RMS values corresponds to a rather small local differences
For high enough data rates and not too narrow filter bandwidth, Hardware and Software phase average are in very good agreement.
EFFECT OF DATA RATE & FBW
FREE SWIRLING JET

At low Data Rate (but high SNR) accuracy of trigger signal decreases

Re = 24400
r = 0 mm
Data Rate 1217 Hz
EXPERIMENTAL RESULTS
CONFINED SWIRLING JET

Mean tangential velocity profile at nozzle exit

- Tangential Velocity, m/s
- r, mm

Graph showing the mean tangential velocity profile at the nozzle exit with a range of tangential velocities from -30 to 30 m/s and a range of r from -20 to 20 mm.
EXPERIMENTAL RESULTS
CONFINED SWIRLING JET

Signal to Noise Ratio estimated from Hardware Phase Average results

For all data points SNR ~0.25

SNR = \frac{\text{RMS turbulent}}{\text{RMS periodic}}

\text{RMS periodic} = \sqrt{\frac{1}{T} \int_{0}^{T} (\tilde{u} - \bar{u})^2 \, dt}

\text{RMS turbulent} = \sqrt{\frac{1}{T} \int_{0}^{T} (u - \bar{u})^2 \, dt}
A sharp and low amplitude peak (PVC) is clearly visible at 447 Hz.
Other (wider) peaks are visible at 260 Hz and 510 Hz (very close to $f_{PVC}$).

**THIS IS A TOUGH TEST CASE FOR SOFTWARE PA**
EFFECT OF DATA RATE & FBW
CONFINED SWIRLING JET

Both SNR and Filter Bandwidth Significantly affects Software Phase Average:

a) Low SNR!

b) Peak in the spectra at 510 Hz (very close to $f_{PVC}$)
Even for this *tough test case* Software Phase Average gives quite good results by a appropriate choice of FBW.
Software and Hardware Phase Average techniques have been applied to different experimental LDV data-sets (swirling flows showing a PVC instability), and the results have been compared.

Effects of re-sampling frequency (trigger generation) is negligible when its value is at least \( > 20 f_{PVC} \).

High SNR test case:
- Very good agreement between Hardware and Software PA
- High LDV data rate: results depend very slightly on filter bandwidth
- Low LDV data rate: results can be significantly affected by filter bandwidth

Low SNR test case:
- Good agreement between Hardware and Software PA by a proper choice of filter bandwidth
- Higher influence of FBW as compared to the High SNR test case
  - Low SNR
    - presence of peak (in the velocity PSD) close to that of PVC

Energy of random velocity fluctuations contained in the filter bandwidth appears in the phase average as a coherent periodic signal.
- Amplitude of phase averaged velocity increases as FBW increase
HIGH SNR (> 0.5) AND HIGH DATA-RATE (>4-5 \(f_{\text{periodic}}\))

Software PA gives very good results as compared to Hardware PA

Quite small influence of FBW on phase average results

LOW SNR (<0.5)

Software PA can give good results by appropriate choice of filter bandwidth

A criterion to select the appropriate bandwidth should be related to the shape of velocity PSD