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A HIGH FREQUNCY MULTIPLET – A NEW STATE IN THE TRANSITION REGIME OF THE CYLINDRICAL TAYLOR-COUETTE SYSTEM

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Abstract

A high frequency multiplet has been investigated quantitatively. The spatio-temporal velocity profiles of the axial velocity component $V_z(z,t)$ were obtained using the ultrasonic Doppler method and analyzed by space dependent Fourier Transform. From the multiplet frequency structure, as well as the Reynolds number where it appears, we determined that this is a new mode that appears after the classical wavy mode disappears. The spatial distribution of the multiplet exhibits characteristic features which are found to vary from vortex pair to vortex pair, indicating a break in the spatial periodicity of the flow. Furthermore, the multiplet mode is highly concentrated at the outflow boundary, in contrast to the wavy mode which is concentrated more at the inflow boundary.

Introduction

The nature of flow transition to turbulence in a rotating Taylor-Couette system was investigated and reported earlier using spatio-temporal experimental data obtained by the ultrasonic Doppler method[1]. The transition scheme was quantitatively discussed using an excitation curve of each mode with respect to Reynolds number. At the higher Reynolds number, after the quasi-periodic wavy mode disappears, a new mode was found which has a somewhat higher temporal frequency. Using global entropy as well as total energy occupation, this transition scheme was quantitatively evaluated and it was concluded that the turbulent regime for the reduced Reynolds number less than 100 should be called “soft turbulence”.

During the course of this investigation, it was observed that a high frequency multiplet of peaks appeared in the power spectra for some range of the reduced Reynolds number. We report here characteristics of this multiplet in the power spectrum.

Experiment

We used the same experimental setup as was used for the previous investigation[1]. The Taylor apparatus has the following dimensions : inner radius (R_i) is 94mm, outer radius (R_o) 104mm, radius ratio R_i/R_o= 0.904, aspect ratio (column height / gap distance d) 20. Only the inner cylinder is rotated. The Reynolds number is defined as $R=\Omega R_i d/\nu$ (ν kinematic viscosity). A mixture of water and glycerol was used as the working fluid. The critical Reynolds number R_c for this system is 134.57, and the reduced Reynolds number is defined as $R^*=R/R_c$.

The measurement was made using the ultrasonic Doppler method which obtains the time-evolving spatio-temporal velocity field: 128 spatial points (0.75mm interval) and 1024 temporal points (130ms sampling time). Approximately four pairs of Taylor rolls in the middle of the column height were covered for measurement. The measurement in the present investigation was focused on the Reynolds number range R^*= 16~28.

The data set was analyzed by calculating the power spectrum of the time series for each spatial position, thus generating a space dependent power spectrum.

Results and discussion

Power spectrum – averaged for whole region

As in our earlier work, the space dependent power spectrum was averaged over all 128 spatial positions, as shown in Fig.1. In this example, two dominant peaks are seen in the low frequency portion. They correspond respectively to the chaotic broad band component and the wavy mode.

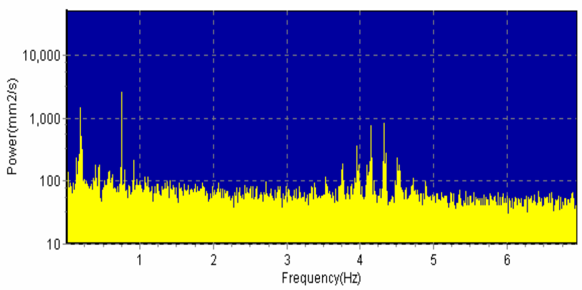

Fig.1 Space averaged power spectrum. R^*=18.1.

In the frequency range for 3.5-5Hz, a multiplet peaks appears, being composed of 8 peaks in this example.

In order to investigate the nature of this multiplet component, the frequency of the peak in the multiplet is plotted in Fig.2 together with the difference frequency between two adjacent peaks. Since the difference is not constant but rather slightly linearly increasing, it is clear that these peaks are not harmonic peaks of any basic mode. At the same time, the difference frequency is very close to the low frequency peak which is identified as the chaotic mode. Consequently, this multiplet component is considered to be strongly related to this chaotic mode. It is also noted here that the frequency of this mode is quite high compared to other fundamental modes of this system.

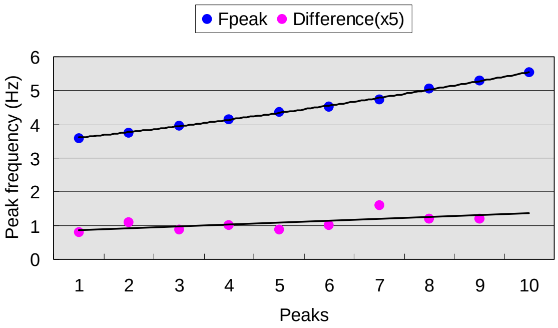

Fig. 2 Peak frequency and the difference frequency between two adjacent peaks in the multiplet. Same data set as for Fig.1. The difference frequency is multiplied by 5 for display purposes.

The total power of the multiplet was computed by summing the power of identified peaks of this power spectrum for the frequency range from 3.4Hz to 4.8 Hz. These values are plotted with respect to the Reynolds number in Fig.3.

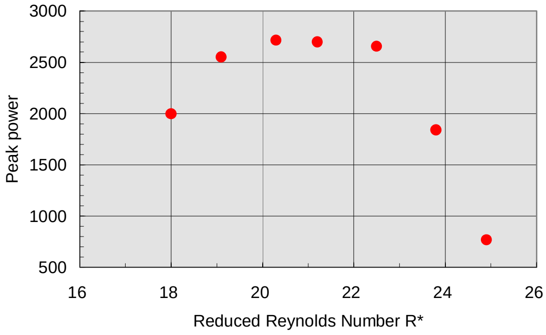

Fig. 3 Excitation curve : Variation of the total power of the multiplet component vs reduced Reynolds number. (Note : the coordinate is linear.)

As shown in this plot, the appearance of the multiplet component is limited to the Reynolds number range 18 to 25. In the excitation curve in the previous report, there was a gap in the excitation curve for this range of Reynolds numbers . This multiplet component fills this gap as shown in Fig.4.

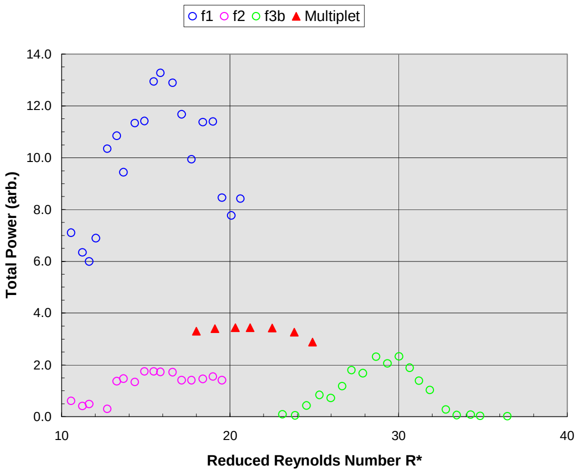

Fig.4 Excitation curve for the transition regime. (Note : The coordinate is in log scale.)

Power spectrum – averaged for a single roll pair.

Fig. 5 shows a space dependent power spectrum. In the low frequency region, there are two lines corresponding to the wavy motion of the Taylor rolls. Their spatial characteristics are more or less identical showing strong peaks on each roll. On the other hand, in the high frequency region, the spatial distribution of the multiplet peaks is seen to be rather broad but localised, showing only 4 spatial peaks.

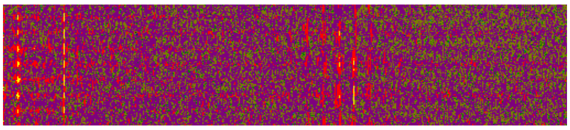

Fig. 5 Spatial dependent power spectrum. R*=18.1.

The power spectrum was then averaged over a single roll pair, as shown in Fig. 6 for three different pairs. The nature of multiplet cannot be resolved very clearly and still includes multiple peaks. However, it is clearly seen that the number of peaks included is less and that the frequency range covered by the multiplet is slightly different from pair to pair. This also indicates that the multiplet mode in one roll pair is independent of the others. Assuming that the main peak inside the multiplet is the one with the largest power, the main peak frequency varies by about 0.2 Hz from one roll pair to the next.

We therefore conclude that the eigenstate of the multiplet component can vary from roll pair to roll pair. Up to now, it has been a priori considered to be correct to assume an axial periodicity. Experimental studies as well as numerical studies have been studied for a single pair and never paid attention to a break of this assumption.

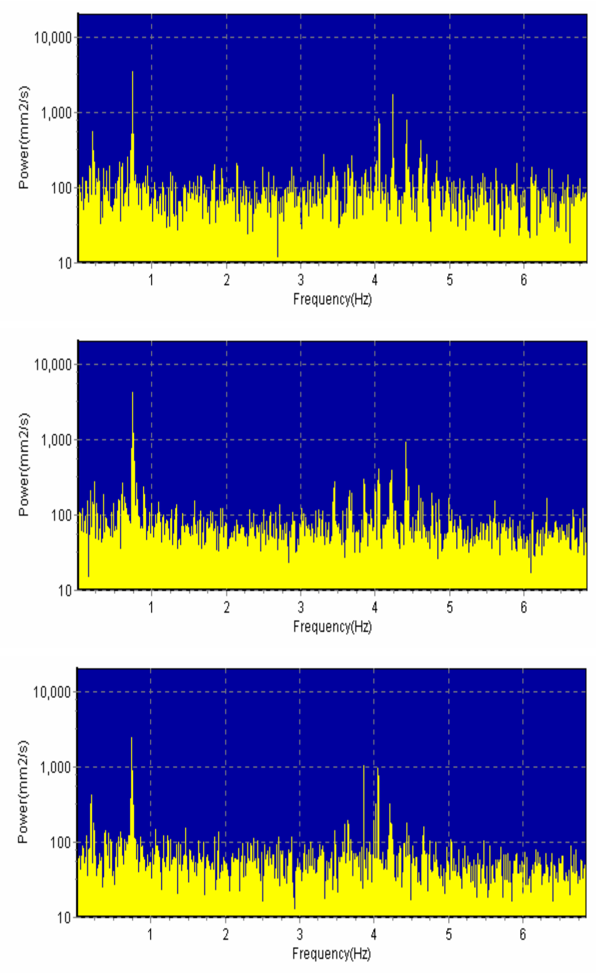

Fig.6 Power spectrum averaged over a single roll pair, displaying only 3 pairs.

Spatial distribution

The spatial characteristics of two frequency components are given in Fig. 7 & 8. Fig.7 shows the distribution of a single peak component of the frequency 0.736Hz which represents a Wavy Vortex Flow mode. The power is large at both inflow and outflow boundaries but much larger at the inflow boundary. The distribution is simple being concentrated in a narrow region.

Fig.8 shows a spatial distribution of the multiplet components. The sum of the peak power for the frequency range 3.4 to 4.8Hz is plotted. It shows, in contrast to Fig.7, a very characteristic distribution. Namely, it appears only at the outflow boundary, but the distribution is broad. A relatively large power is distributed over a wider axial distance and then forms a sharp peak on top of it.

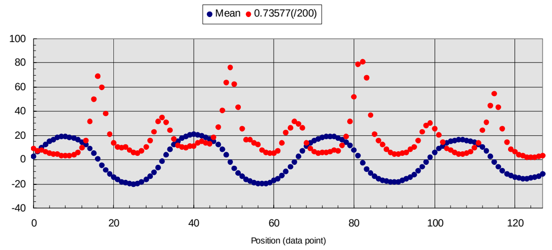

Fig.7 The spatial distribution of a single frequency component; 0.736Hz. Blue points represent the time average velocity distribution, for easy identification of the spatial structure.

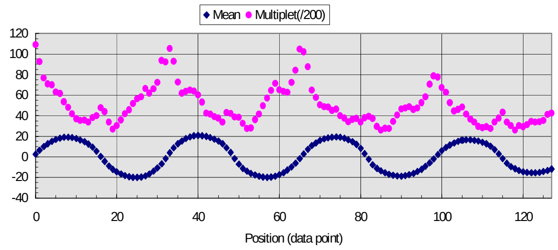

Fig.8 The spatial distribution of the power for the multiplet component.

As the behaviour of the axial velocity component, V_z, is more strongly affected by the radial velocity component V_r at the outflow boundary, such a strong nonlinear behaviour of the multiplet component is thought to be due to an energy exchange between two velocity components. This will be studied in future work.

Concluding remarks

A flow mode, which appears as a multiplet in the power spectrum, was investigated for the Reynolds number range 16-28. The space averaged and space dependent power spectrum was used to identify this mode in the transition regime of this flow configuration. We draw the following conclusions :

- The multiplet is composed of 7 to 10 sharp peaks.
- Frequency difference between adjacent peaks is not constant, but linearly increasing with peak frequency.
- Clearly, this component is not a harmonic wave of any basic mode.
- From the excitation curve for this mode, we have determined that the multiplet is a new mode which appears after the disappearance of the Wavy and Modulated Wavy modes, but before the appearance of the Fast Azimuthal mode (see [1]).

- The mutiplet structure is different for different roll pairs, indicating that each roll pair can take on a different eigenstate. This may imply a resolution of a degeneration of the state or a break of spatial periodicity in the axial direction.
- The spatial distribution of the multiplet component shows that it appears strongly at the outflow boundary, in contrast to the Wavy mode, and from the shape of distribution, it was supposed that this nonlinear mode might be strongly correlated to the radial velocity component.

Acknowledgements

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References

[1] Takeda, Yasushi, 1999, "Quasi-periodic state and transition to turbulence in a rotating Couette system. " JFM, 389:81-99.