Geophysical Research Abstracts
Vol. 19, EGU2017-15707, 2017
EGU General Assembly 2017
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Sub-harmonic frequency lock-in and vortex shedding synchronization due to regular and irregular surface waves.

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The influence of both regular and irregular surface waves on a turbulent Von Karman vortex street has been investigated experimentally with the help of the phase modulation of the signals. The experiments have been performed in a hydrodynamic flume, where the Von Karman Street created behind a vertical cylinder is created by a steady current. The surface waves propagating upstream are excited by a computer controlled wave maker. It is found that the regular surface wave can give rise to different regimes of vortex shedding in the Von Karman Street: Sub-harmonic frequency lock-in arise if the frequency of the wave is approximately two times that of the vortex shedding frequency. We also observed another regime called harmonic frequency lock-in when the shedding frequency coincides with the frequency of the surface wave.

Phase synchronization can also be obtained with irregular surface waves. In this case, the peak frequency of the applied surface wave spectrum is twice that of the vortex shedding frequency. The relationship between the vortex shedding frequency and the amplitude of the surface waves has been studied. It was found that an increase in the amplitude of the applied waves causes the shedding frequency to decrease and tends to half of the frequency of the applied wave. For a more detailed study of this effect, Hilbert transformation is applied. Using this transformation, the continuous phases of the surface waves f_w and that of the Von Karman vortex street f_k are calculated. The relation between the phases combination F= $2f_k$- $f_w$and the surface wave amplitude is studied. It was found that the time-evolution of F has a step-like shape. The time interval of F having a slope around 0, corresponds to synchronization-like effect. This explains the changes obtained in the spectrum of the turbulent vortex shedding with an increase in the amplitude of the irregular surface waves.

We then decided to compare the evolution of the scouring and the sandy patterns created in the wake of the cylinder for three different regimes: current only, sub-harmonic frequency lock-in and harmonic frequency lock-in. For each regime the time evolution of the bed profiles have been observed in a region of 1mx0.35m around the cylinder. It was found that sub-harmonic frequency lock-in regime leads to the intensification of vortices and the formation of a more regular sand ripple structure behind the cylinder compared to that created by current only. Furthermore, in the harmonic frequency lock-in regime, the sand ripples generated are more important than in the first and second regimes. We can observe that the increase in sand ripples is due to the intensification of vortices in the wake of the cylinder caused by surface waves.

Keywords: Surface waves, von Karman Street, Frequency lock-in, Synchronization, Scouring