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Problematics of aerodynamic damping calculation from measured data of 5-blade cascade

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Aerodynamic damping as a function of inter-blade phase angle (IBPA), so called S-curve, is crucial for assessment of aeroelastic stability of blade cascades, e.g. turbines, compressors, etc. For constructing the S-curve, the motion-induced controlled flutter is introduced to the blades of the cascade. As decribed in [2], two testing methods exist: aerodynamic influence coefficient (AIC) approach and travelling wave mode (TWM) approach. In TWM approach, all blades in a row oscillate with the same frequency and amplitude with various IBPAs. The response is measured only on the reference blade. With this approach, several measurements with different IPBAs are needed to construct the S-curve. On the other hand, AIC uses single oscillating blade and principle of linear superimposition of aerodynamic influence responses measured on all blades in a cascade. The result of one single measurement can be used for estimation of aerodynamic damping for any IBPA.

In the past year a new 5-blade cascade with rotating symmetrical NACA 0010 profiles was designed and built. The blades of the cascade were placed further apart and thus we are now able to reach stall flutter. Also, the suspension of the blades and sensors were significantly improved. Now, our goal is to evaluate S-curves using AIC approach for different flow conditions and oscillation frequencies.

In AIC approach only the middle blade oscillates. Motion of the oscillating blade is measured by laser vibrometer; its moment and moment of two adjacent blades is measured by strain gauges placed on the blade shafts. The aerodynamic moment generated by the flow and acting on the oscillating blade, however, cannot be easily measured as the measured signal also contains moment generated by inertia and damping of the blade. Two methods of extracting the aerodynamic moment from the measured signal, subtraction and identification methods, were used on the previous blade cascade and are described in [1].

Subtraction method subtracts the moment measured with oscillations without the flow from the moment measured with the flow. The disadvantage of this method is that each measurement must be repeated with and without the flow and its accuracy is limited to the cases where the motion of the blade is not affected by the flow.

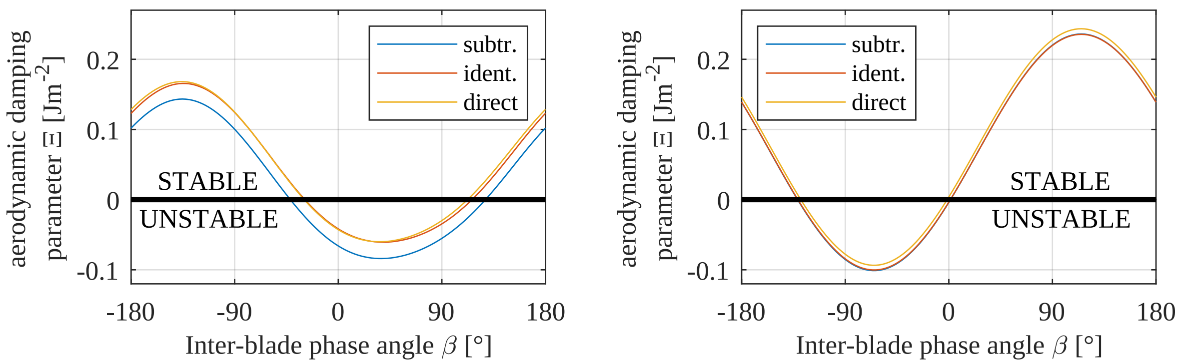
Identification method is based on identification of the blade inertia and damping from measured data without the flow and using those identified parameters to calculate structural moment using measured motion and subtract it from the measured moment. The advantage over the subtraction method is that only one measurement without the flow is needed and also it is not sensitive to the disturbances in the motion caused by the flow.

Both of those methods, however, subtract a small aerodynamic moment caused by the damping of the air present around the blades in measurements without the flow. They would need to be performed in the vacuum to overcome this issue.

In the new cascade the blade attachment is made with as less damping as possible. With the forced excitation, the only structural damping is caused by deformation of the blade and its shaft and by friction in pin bearing. This structural damping is assumed to be lower then the damping by surrounding air mentioned above. And since the S-curve is calculated from the work per cycle and the inertia of the blade is not generating any work, it is reasonable to integrate the work per cycle directly from the measured moment. Moreover, this direct method is the upper boundary of the true result – no structural nor aerodynamic damping is subtracted, while the two previous methods are the lower boundary – both aerodynamic damping from steady air and the structural damping are subtracted.

Experiments were conducted on the cascade with angle of attack -10°, wind speed 25 m/s and various oscillation frequencies. S-curves were evaluated using all three mentioned methods and compared. Fig. 1 shows comparison of the methods for oscillation frequencies 10 and 40 Hz. In the case when the motion is not disturbed by the flow, subtraction and identification methods should give the same results, as they do for 40 Hz in Fig. 1b. However, this is not true for 10 Hz in Fig. 1a where the S-curve evaluated by subtraction method is shifted downwards and is not correct. As it was mentioned above, the identification (or subtraction) method should be a lower boundary of the true result and direct method the upper boundary. When we look both on Fig. 1a and Fig. 1b, the shift between those two curves is negligible.

This brings us to a conclusion that with the new cascade it is possible to evaluate aerodynamic damping by directly integrating the measured moment to obtain work per cycle. By doing so we can avoid errors caused by imprecise subtraction or identification.



(a) Oscillation frequency 10 Hz

(b) Oscillation frequency 40 Hz

Fig. 1. Comparison of S-curves evaluated by three different methods

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References

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