CONTROLLING AND TESTING A FLAP SYSTEM FOR GENERATING GUSTY CROSSWINDS IN WIND TUNNEL EXPERIMENTS

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Abstract

A flap system for the generation of gusty crosswinds in a closed return wind tunnel with closed test section was developed. The system consists of four wings with oscillating flaps. This paper describes the construction of a first prototype of a single oscillating flap, which includes the programming of the drive and the mechanical testing of the flap movement. The flap is required to oscillate sinusoidal with a frequency of 50Hz. Therefore, the system is analysed by using a laser Doppler vibrometer. In the process the flap movement is examined with a frequency of a maximum of 50Hz and an amplitude of a maximum of 3°.

The results show an adequate movement of the flap concerning the programmed frequency, depicting that the amplitude of the oscillation seems to be frequency-dependent. The specified amplitude varies about 20% of the intended value. During this process, no relevant deformations of the mechanism were measured.

Keywords: Wind tunnel; prototype; flap system; oscillation; gusty crosswinds.

1. Introduction

Examining flow conditions for a certain application can require a combination of different approaches. This includes experiments in wind tunnels, field measurements and numerical simulations, which are important methods besides the analytical theory [1]. One issue of wind tunnel experiments is the difficulty of simulating unsteady flow conditions like gusts over a useful frequency range [2]. Gusts can occur for example at tunnel exits, passing trains or just randomly due to weather conditions. Taking unsteady flow in wind tunnel experiments into account helps to reproduce more realistic wind conditions. To define a repeatable and comparable basis for gust generation this research focuses on harmonic oscillations of the flow direction in the range of the test section of a wind tunnel. The harmonic oscillation is defined via its frequency and its amplitude which describes the maximum deflection of the flow direction. Increasing the frequency usually requires a reduction of the amplitude if the motor power and the moment of inertia are invariable. The only

variable is the acceleration which is calculated as a product of the amplitude and the square of the angular velocity. Researching flap based systems for gust generation revealed a maximum frequency of about 12.5Hz along with an amplitude up to 2° [3] and a maximum amplitude of about 10° in combination with a frequency of about 5Hz [4]. Patel and Hancock [3] use for example an electro-hydraulic servo-mechanism for displacing movable plates at the nozzle outlet.

This contribution focuses on the development of a more dynamic system which should oscillate with a frequency of 50Hz and an amplitude of 3° . The system consists of four wings with oscillating flaps for generating gusty crosswinds in wind tunnel experiments. To fulfil the dynamic requirements the moveable flaps are built as small and light as possible. The wings of this system get vertically placed at the beginning of the test section of the crosswind test facility in Göttingen. This facility is used, among other things, to test the crosswind stability of trains [5]. The moveable flaps of the wing system should induce oscillating flow conditions for the test model by deflecting the flow direction and cause a variation of the wind's angle of attack. For testing the feasibility of the system a prototype of a single flap is built. Thereby it is to be examined, whether the fast oscillating flaps can be driven directly with a common industrial servomotor. This includes the programming of the control unit and the mechanical testing of the flap movement with a laser Doppler vibrometer which is presented in this paper.

2. Theoretical background

The crosswind test facility at the German Aerospace Center, Göttingen is equipped with a rotary table which allows testing the crosswind stability of a train model under different yaw angles in the stationary flow of the wind tunnel. Thereby the direction of inflow is steady and no unsteady flow conditions are taken into account. Several articles have determined unsteady effects and higher forces and moments on cars compared to steady inflow conditions triggered by specific frequencies of gusty crosswinds [6–10]. If the induced wave length corresponds for example with the length of the train model, a higher yaw moment than with steady inflow will be measured as opposite lateral flow components appear in the front and the back part of the model (see fig. 1).

On the one hand, this describes the need for unsteady test conditions for certification procedures of high-speed trains which could, in turn, increase the safety standards in the future. On the other hand, the higher yaw moment is the reason for the frequency requirement of 50Hz. Train models are usually scaled by 1:25. Assuming that a train model with the length of 1m is placed in the test section and the flow velocity is 50m/s, a frequency of 50Hz is necessary in order to get a wave length which corresponds to the model length.

Fig. 1. Concept of oscillating flaps in the test section of the crosswind test facility for generating sinusoidal crosswinds in wind tunnel experiments (view from above)

Results from preceding simulations of the developed flap system with OpenFOAM show its potential. Fig. 2 illustrates the wake flow behind a two-wing system. The simulation was performed with oscillating flaps with a frequency of 100Hz and an amplitude of 5° . The velocity vectors of the flow are stretched ten times along the ordinate to make the induced variation of the flow direction visible. The depicted parameter α describes the current angle of deflection in degrees in relation to the direction of the main flow. The rotation axis of the flaps are located at a test section length of 0m. The deflection still exists in a sufficient extent up to 1.5m after the flaps. These results led to next step of building a prototype.

Fig. 2. Results from a flow calculation of a two-wing system by a general flow velocity of 40m/s

3. Materials and Methods

In the following section, the approach for building and testing the prototype is described. For the dimensioning of the drive chain, a sine function for describing the oscillation is used. The required motor torque is calculated via the necessary acceleration and the moment of inertia of the drive chain. A servomotor with supplementary equipment is chosen accordingly: A synchronous servomotor from Beckhoff (AM8036-0L0A) and an embedded PC (CX5130-0120), which is acquired for driving the flap system. For programming the industrial PC the engineering software TwinCAT3 is used. The industrial PC functions as a Programmable Logic Controller (PLC) which gives position command values to the servo module.

For measuring the flap movement, a laser Doppler vibrometer (LDV) from Polytec is used. The LDV consists of an OFV-5000 controller and an OFV-505 sensor head. The signals are analysed by using Matlab R2012b.

4. Practical Realization

The main structure of the prototype consists of aluminium profiles where the servomotor is attached to a mounting plate in the centre of the top of the structure. The flap system (see red arrow in fig. 3) is located on the top of the main structure and is connected to the servomotor (see green arrow in fig. 3) by a metal bellow coupling (see yellow arrow in fig. 3). It consists of a split NACA0018 airfoil where the front part (grey) is fixed and the rear part (black) acts as a moveable flap. The moveable flap makes up a third of the chord length. It is made out of carbon fibre and a steel shaft is pasted into it at each end and is guided by a slide bearing. The wooden plate makes up part of the bottom of the wind tunnel. The whole drive is placed beneath the wind tunnel and the vertical flap is about half the height of the test section ($h_K = 800\text{mm}$).

Furthermore, a control program and a user interface is developed for defining the flap movement. It is possible to specify the desired frequency and amplitude of the sinusoidal oscillation. The amplitude describes the maximum deflection of the flap in degrees. The user can start and stop the flap movement and define the oscillation parameters via a graphical user interface. The program is developed as a finite state machine with six main states. It is therefore not possible to change the settings while the system is running. It is possible to define a maximum frequency of 50Hz and maximum amplitude of 10° . However, the system was tested with a maximum frequency of 50Hz along with a maximum amplitude of 3° in a first approach.

Fig. 3. Construction of the single flap system

For measuring the actual movement of the flap, it is equipped with 23 measuring points at a distance of 75mm from the axis of rotation (see white little markings close to the trailing edge of the flap in fig. 3). The velocity of the flap $v_K(t)$ is determined at each of these measuring points by using the laser Doppler vibrometer and logged synchronous with the actual position signal from the encoder system of the servomotor $\alpha_{act}(t)$. A resolver serves as an encoder system in the utilised servomotor and returns the actual position of the rotor shaft in degrees. Analysing the phase differences of these signals for different movement parameters makes it possible to form a statement about the rigidity of the drive chain as a possible torsion results in a measurable change in the phase differences.

5. Results

At first, a Fast Fourier Transformation (FFT) is applied on the velocity signals $v_K(t)$ from the laser Doppler vibrometer to verify the frequency f of the movement. The set frequency f is properly met as it constitutes the highest spectral component $|v_K(f)|$ of the underlying velocity signal (see fig. 4). The achieved frequency of $f = 50\text{Hz}$ of the moveable flap exceeds the dynamic of all researched gust generating systems. The frequency is often a limiting factor in practical applications as it is usually connected to a reduction of the amplitude and reaches mechanical limits [11].

Fig. 4. Frequency spectrum $|v_K(f)|$ of the velocity signal $v_K(t)$ for an oscillation with a frequency of $f = 50\text{Hz}$ and an amplitude of $\hat{\alpha} = 3^\circ$

The next step is to test the actual amplitude $\hat{\alpha}_{act}$ for different frequencies f . This is done by calculating the actual amplitude from the position signal $\alpha_{act}(t)$ and depicting its ratio to the set amplitude ($\hat{\alpha}_{act}/\hat{\alpha}$) over the frequency f . The results of this examinations show a strong frequency dependence of the amplitude $\hat{\alpha}_{act}$ (see fig. 5). The achieved amplitude of the system of over 2° at a frequency of 50Hz exceeds the dynamic characteristics of the presented systems in the introduction.

Fig. 5. Ratio of the actual amplitude of the resolver to the set amplitude ($\hat{\alpha}_{act}/\hat{\alpha}$) over the frequency f (measured at the lowest measuring point, see fig. 3)

The actual amplitude $\hat{\alpha}_{act}$ overshoots the via the user interface defined amplitude $\hat{\alpha}$ by more than 20% in a frequency range of $f = 20\text{--}25\text{Hz}$. As from $f = 25\text{Hz}$ onwards the amplitude $\hat{\alpha}_{act}$ decreases continuously. The source of these deviations is not explicitly clear but may be found in the internal control system of the servo module. By checking the phase differences between the velocity signal of the lowest measuring point and the resolver signal the torsion in the coupling can be approximated. This analysis shows just very little twisting angles in the coupling which can be neglected.

The final step concerns the torsion of the flap. The variation of the amplitude along the flap span is determined by integrating the velocity signal of the laser Doppler vibrometer $v_K(t)$ of each measuring point. The resulting distance signal describes the travelled path of the related measuring point. Dividing the amplitude of this oscillating distance signal by the radius (75mm) approximates the amplitude of the flap $\hat{\alpha}_K$. A variation of $\hat{\alpha}_K$ along the flap is linked to a torsion of it. Fig. 6 shows the torsion along the flap for different frequencies. By a frequency of $f = 50\text{Hz}$ a stationary wave with a node at a span of $h_K = 750\text{mm}$ is depicted (see red line in fig. 6). The examined differences show a maximum value of 0.1° .

Fig. 6. Torsion along the flap span h_K indicated by the difference of the amplitude $\hat{\alpha}_K - \hat{\alpha}_K(h_{K,1})$ at a set amplitude of $\hat{\alpha} = 3^\circ$ and different frequencies

6. Conclusion

This paper addresses the problem of generating gusty crosswinds in wind tunnel experiments. Using oscillating flaps for simulating gusts demands a high dynamic drive chain. Gust generators described in previous literature do not fulfil the frequency requirements of the German Aerospace Center. Therefore, a new flap system was developed. The flaps are smaller and lighter in order to reduce their moment of inertia. The building and testing of a prototype with a single flap is described in this paper. The single flap is successfully driven by a common industrial servomotor and programmed via a PLC.

The prototype is able to carry out sinusoidal oscillations with an adjustable amplitude and frequency. It is able to oscillate with a frequency of up to 50Hz and an amplitude of up to 3° which exceeds the dynamic characteristics of the researched gust generators. The set frequency gets properly transformed whereas the amplitude shows significant variations which should be considered in future wind tunnel experiments. All measured torsions are insignificantly small. The rigidity of the coupling and the flap can therefore be seen as sufficient. It is assumed that the small twisting angles of the flap will not cause disruptive flow effects in future wind tunnel tests. Further research includes the validation of the system in the wind tunnel by measuring its flow effects for example with hot-wire anemometers.

7. References

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