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경계층 유속 정밀도 증가를 위한 전자파 간섭 최소화 연구

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Study on Minimizing Electromagnetic Interference to Capture Vortex Structures in Turbulent Boundary Layer

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요 약 난류 경계층 내부 와류 구조물 형상을 측정하기 위해 열선 유속계(Hot-wire sensor)를 스테퍼 모터 컨트롤러(Stepper motor controller)에 고정하여 측정 지점으로 이동시켰다. 유동장 내 표면 근처 유속은 상대적으로 느려 차후 측정 데이터 해석 시 신호처리 과정에서 전자파 간섭으로 민감하게 반응하게 된다. 전자파 잡음은 주로 컴퓨터나 기타 전자 장비의 전원 공급에서 발생하는데, 실험 장비 중 전원이 활성화된 스테퍼 모터(Stepper motor)에서 전자파 잡음이 열선 유속계와 연결된 BNC 케이블로 유입되었다. 이는 열선 유속계를 이동시키기 위해 모터 컨트롤러(Motor controller)에 전원 공급이 인가되면, 오실로스코프 화면에 전자파 잡음이 나타나는 것을 확인하였다. 열선 유속계에서 측정된 데이터에 예상치 못한 잡음이 포함될 가능성이 있으므로, 이를 감소시키고 측정 과정에서 신호대 잡음비(Signal-to -Noise Ratio, SNR)를 향상하도록 연결 케이블을 차폐시키고 전자파가 차단되는 컴퓨터로 교체하였다.

• 주제어 : 열선 유속계, 전자파 간섭, 신호대 잡음비, 와류 구조물, 난류 경계층

Abstract To measure the vortex structures within the turbulent boundary layer, a hot-wire sensor was mounted on a stepper motor controller and moved to the designated measurement points. Near the surface within the flow field, the velocity is relatively slow, making the measurements highly sensitive to electromagnetic interference (EMI) during signal processing. This EMI primarily originates from the power supplies of computers and other electronic equipment. In our experimental setup, EMI was introduced into BNC cables connected to the hot-wire sensor from the powered stepper motor. When power was supplied to the motor controller to move the hot-wire sensor, EMI appeared on the oscilloscope screen. Consequently, unexpected noise was present in the data measured by the hot-wire sensor. To mitigate this and enhance the signal-to-noise ratio (SNR) during measurements, the connecting cables were shielded, and an old computer without EMI shielding was replaced.

• Key Words : Hot-wire sensor, Electromagnetic interference(EMI), Signal-to-Noise Ratio(SNR), Vortex structure, Turbulent boundary layer

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Ⅰ. Introduction

Researches on turbulent boundary layers is crucial in the advancement of understanding for fluid dynamics and improving engineering applications. Turbulent boundary layers, characterized by chaotic and irregular vortex regeneration, play a key role in numerous industrial and environmental processes. Accurately measuring these turbulent structures necessitates sophisticated instrumentation. Hot-wire sensors, known for their high frequency response and sensitivity, are often employed to capture minute fluctuations within the boundary layer. To precisely position these sensors within the flow, stepper motor controllers are used, providing the necessary control and repeatability. Signal acquisition is facilitated by BNC cables, ensuring reliable transmission of data between sensors and Analog-to-digital converters (ADCs).

An important aspect of this research is to make clear the vortex structures near the wall, where the flow velocity is low and difficult to measure within turbulent boundary layers [1]. The measurement process is also hampered by noise and electromagnetic interference. Therefore, effective noise reduction techniques [2-6] are crucial to enhance the signal-to-noise ratio (SNR), ensuring that the data accurately represents the turbulent phenomena without extraneous distortions [7]. The purpose of this research is to develop and validate a measurement system that effectively captures vortex structures of turbulent boundary layers while minimizing the signal interference.

Ⅱ. Experimental Set-up and Noise reduction

2.1 Wind tunnel and Hot-wire sensor

Experiments were carried out in an open-return wind tunnel with a 4m-long test section. The wind tunnel was driven by a motor and fan. The boundary layer was tripped at the end of the contraction section to ensure a fully developed turbulent boundary layer over a flat test surface. A trip device consisted of a zigzag array of 3mm-high circular cylinders of 5mm diameter mounted over a 1mm thick rubber strip, 64mm-wide. The turbulent flow field was measured with a hot-wire sensor (Dantec 55P15) of boundary-layer type in an open-return wind tunnel. The sensor has a 5μm diameter, 1.25mm long platinum-plated tungsten wire shown in Fig. 1.

The hot-wire sensor was operated at the overheat ratio of 1.8 with a Dantec 56C Constant Temperature Anemometry (CTA) system. The analogue signal from the CTA unit was converted to 16-bit binary format by an IOTech ADC 488/8SA analogue-to-digital converter at a sampling speed of 1kHz before it was sent to a personal computer (PC) for analysis. An automatic traverse mechanism was used to position the hot-wire sensor at grid points in three axes, controlled by stepper-motor controllers with an IEEE-488 interface.

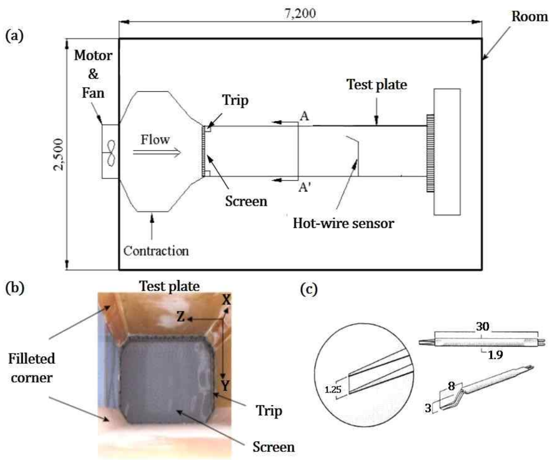

Fig. 1. An open-return wind tunnel (a) cross section view (b) A-A' view looking upstream (c) A hot-wire sensor (55P15), All dimensions in mm

Measurements of the boundary layer were taken 2.7m downstream of the inlet of the test section, where the boundary layer thickness was δ=60mm (δ^+=430). The free-stream velocity was U_∞=2.5m/s with a turbulence intensity of 0.35%. The Reynolds number based on the free-stream velocity and the streamwise distance measured from the test section inlet was

4.5×105, while Reynolds number based on the friction velocity and the boundary layer thickness was 430.

2.2 Traverse System and Electronic Noise Reduction

An automatic traverse mechanism was used to position the traversable sensor at grid points in three axes, which was controlled by a stepper-motor controller with an IEEE-488 interface. Due to the importance of near-wall data, it has the resolution of 1.25μm in the wall-normal direction and 2.5μm in the streamwise and spanwise directions. It has been noted that electronic noise appears on the oscilloscope when the traverse power supply is energised. It suggests that the data taken from a hot-wire sensor may contain unexpected noise, which needs to be reduced to increase the signal to noise ratio(SNR) in the measurements. The electronic noise usually comes from power supply, of a computer or other electronic equipments. The stepper-motors also radiate electro-magnetic noise when energised. Each noise source had been investigated by sampling them with an IoTech 488/8s ADC at 50 kHz and 1kHz. Here, the hot-wire sensor was placed inside the wind-tunnel at the center of the test section in static air.

Fig. 2 shows the hot-wire signal taken by the ADC at 50kHz in static air. When the traverse was energized, high frequency(5kHz) noise is introduced, in Fig. 2 (b) and Fig. 3 (b), on the hot-wire signal. It was suspected that the cables connecting the controller with the stepping motors were not properly shielded. These cables may have received high frequency noise by acting as an antenna to the hot-wire sensor and CTA during data acquisition. To prevent this frequency, Raybriad-101 cable screening braid was applied over the whole cable length and each end of the screened cables was earthed to the same ground.

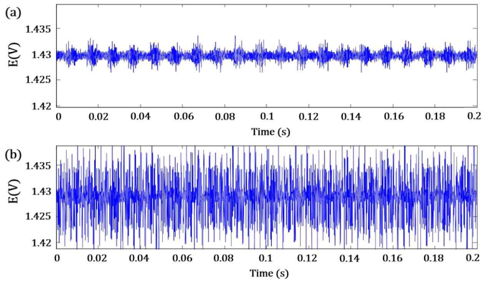

Fig. 2. Hot-wire signal on the ADC at 50kHz before shielding cables. (a) computer on and traverse power off (b) computer and traverse power on

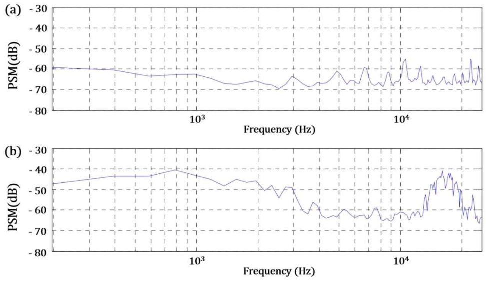

Fig. 3. The power spectrum magnitude (PSM) of Fig. 2 (a) computer on and traverse power off (b) computer and traverse power on

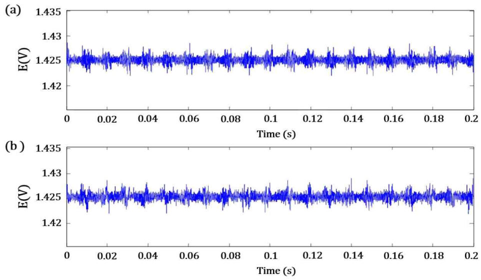

Fig. 4. Hot-wire signal on the ADC at 50kHz after shielding cables (a) computer on and traverse power off (b) computer and traverse power on

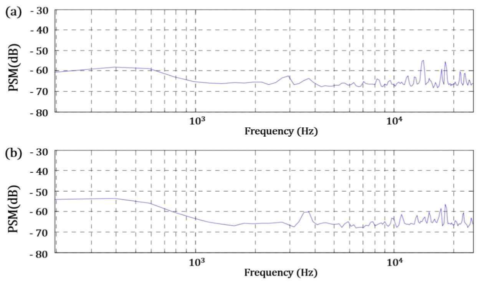

Fig. 5. The power spectrum magnitude (PSM) of Fig. 4. (a) computer on and traverse power off (b) computer and traverse power on

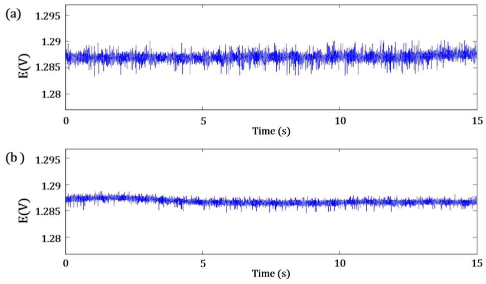

Fig. 6. Hot-wire signal on the ADC at 1kHz after shielding cables (a) With old computer (b) with new computer.

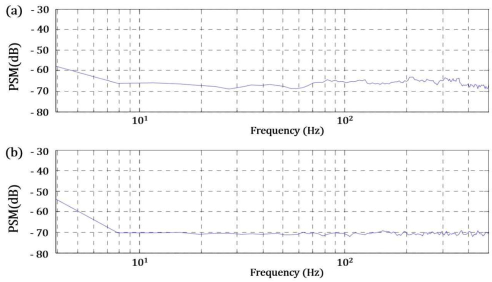

Fig. 7. The power spectrum magnitude (PSM) of Fig. 6. (a) With old computer (b) with new computer

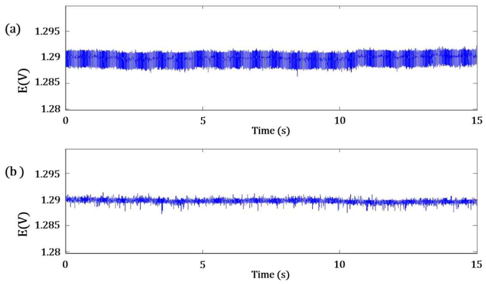

Fig. 8. Hot-wire signal on the ADC at 0.08m/s free-stream velocity
(a) 100kHz sampling rate
(b) 1kHz sampling rate.

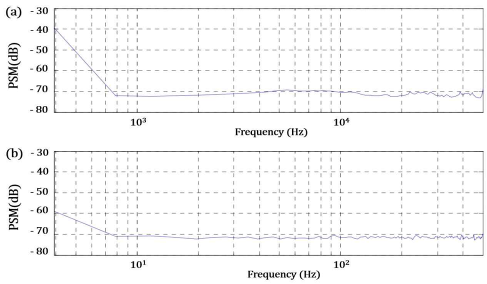

Fig. 9. The power spectrum of Fig. 8

(a) 100kHz sampling rate (b) 1kHz sampling rate.

Fig. 4 and Fig. 5 show the hot-wire signal taken after shielding. The high frequency noise was being reduced significantly on energizing of the traverse by the shielding cables. Nevertheless there remained a low frequency noise as shown in Fig. 6 and Fig. 7. Fig. 6 (a) shows the hot-wire signal sampled at 1kHz with the wind-tunnel running to give a free-stream velocity of 0.08m/s which contained low frequency noise. It was thought that the power supply of the computer interferes with the hot-wire sensor and the CTA at low frequency. Thus the computer was replaced to reduce the low frequency noise shown in Fig. 7 (b).

Finally, data was sampled at 100kHz and 1kHz to check the noise level in the signal with the wind-tunnel running at 0.08m/s. Fig. 8 and Fig. 9 show these sampled signals with time series and Power Spectrum Magnitude(PSM). The following Table 1 summarized the peak to peak voltage level of the hot-wire sensor with the various noise reduction techniques used.

Table 1. Peak-to-peak hot-wire voltage with various conditions

Condition	Pk-Pk ADC Signal
Traverse on, old computer, without shielding @ 50kHz	31.5mV
Traverse on, old computer, with shielding @ 50kHz	7.2mV
Traverse on, old computer, with shielding @ 1kHz	7.0mV
Traverse on, new computer, with shielding @ 1kHz	4.3mV
Traverse on, new computer, with shielding @ 100kHz	6.0mV
Traverse on, new computer, with shielding @ 1kHz	4.1mV

Fig. 10 shows that energy spectra sampled at 1kHz with 2.5m/s free-stream velocity, at different wall normal positions. This result indicates that the noise level is negligible to perform an elaborate experiment in a wind tunnel and the sampling rate of 1kHz can capture turbulence in the boundary layer with an upper frequency limit of around 500Hz. In free-stream region, the low frequency is 4 decade smaller than the most active region such as the viscous and buffer region and is almost 0.01% of the magnitude. Thus, it is negligible.

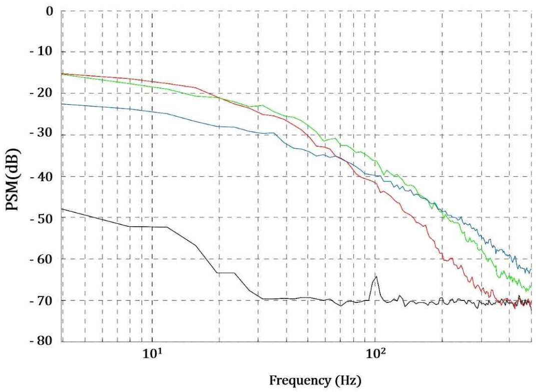

Fig. 10. Energy spectra for the viscous region (red), buffer region (green), log region (blue) and free-stream region (black).

III. Conclusions

In this study, the experimental data were stored on a computer connected through BNC cables, which acted like antennas and received noise, making the assessment of electronic noise crucial for obtaining reliable signals. After shielding the BNC cables with the Raybraid-101 cable screening braid, high-frequency noise from the power of stepper motor was significantly reduced. In addition, low-frequency interference from the computer was also mitigated. As results of shielding cable and replacing computer, the peak-to-peak voltage magnitude on the ADC signal decreased by a factor of 8, and the power spectrum magnitude was reduced by 2 orders of magnitude compared to the previous setup. These improvements ensure that the data collected can be analyzed with increased reliability and accuracy.

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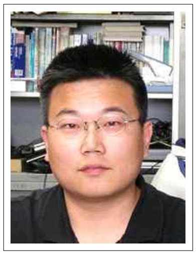

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