Mode Selecting Control of 2D Roll-Cell by Pulsed Jets

Kakuji OGAWARA
Shin-ichi TAHARA and Masato Nakayama
Faculty of Engineering , Hokkaido University
N13,W8 Kita-ku
Sapporo, 060-8628 JAPAN

ABSTRACT

Experimental and numerical studies were conducted to examine an idea of selecting a roll-cell pattern in 2D flow among many possible stable states. Neural networks(NN) were applied in order to recognize a certain flow pattern. And Pyragas' delayed feedback control(DFB) theory is used to overcome the instability caused by process time delay of feedback loop. Notable approach of this study toward active control of fluid flow is that suitable control rule and control parameters can be chosen by way of judging the flow pattern or flow state. To selecting a certain mode of flow, particle image velocimetry(PIV) is utilized for estimating flow field, then NN switches to the suitable control rule for stabilizing the mode. 3D numerical simulations were also carried out in order to find optimal parameters of Pyrags control.

INTRODUCTION

Although many attempts of turbulence active control have been made, most of those experimental studies experience "out of control" state in the case of using large feedback gain. In the present study, we assume this "out of control" state as chaos, and resort to use chaos control theory to prevent the flow field from falling into "out of control" state. We found that Pyragas' DFB was reasonably effective to stabilize a control system which resonates because of feedback phase delay. This technique is seemed to be essential for flow control system, because our control algorithm and hardware is rarely fast enough to cope with turbulence. However, Pyragas' DFB has a drawback. If the targeting flow field has multiple stable state, we have no way of knowing which mode will be obtained as the final state. In other words, Pyragas' DFB can stabilize the flow control system, but the resulting stable mode may not be the mode we wanted. This difficulty might be due to the fact that the control system is not unconditionally stable but saddle point characteristics. In order to stabilize the control system with saddle point characteristics, sliding mode control theory is known to be effective. This control method is distinguished by the control parameter switching. We adopted the idea of this rule switching to our flow control system for the purpose of selecting a flow pattern among many stable modes.

EXPERIMENTAL APPARATUS AND PROCEDURES

Experiments were carried out for low Reynolds number oil flow in a rectangle thin container, whose aspect ratio is 6:1:0.5. The container was made of plexiglass, the width is 300mm, the hight is 50mm and the depth is 25mm. The diameter of a holes for the actuator jet is 5mm. Four independent pulsed jets were used as actuators in order to keep the circulation of the roll-cell flow in container constant. Each jet is controlled by own control system as shown in Fig.1. Fluid flow was observed using PIV system, and velocities were estimated for 60x10 points by moving least square(MLS) method. Two progressivescan high speed CCD cameras(Photoron *Photocam 120*) were used to visualize four convection cells, therefore , each camera was set for two cells nearby. Each *Photocam 120* was directly connected to a PC(Intel Petium II 300MHz) by way of using specialy designed framegraver borad. Frame rate used for this experiment was 120 frames/sec, and resolution was 640x480 pixels. 180 successive images were directly stored into RAM memory first, then manually stored into removable media.

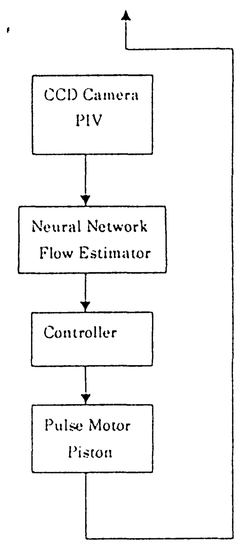

Figure 1. Flow estimation algorithm .

NNs were trained to judge the flow pattern in advance or off-line. Typical flow patters suitable for the current feedback control were taught to be recognized. The NN activate the following control law only for the moment when the flow field is similar to the one trained. Then, Pyragas' DFB control theory was applied to each pulsed jet control unit. Fig.2 is the block diagram of the Pyragas' DFB control. This method is designed to force the system to fall into a limit cycle. Period of the limit cycle is a multiple of arbitrary delay parameter τ . If the period is long and amplitude of the oscillation is small, the system can be considered as stabilized. Finding the optimal value of τ is not trivial task, we conducted numerical simulations to investigate optimal time delay and feedback gain.

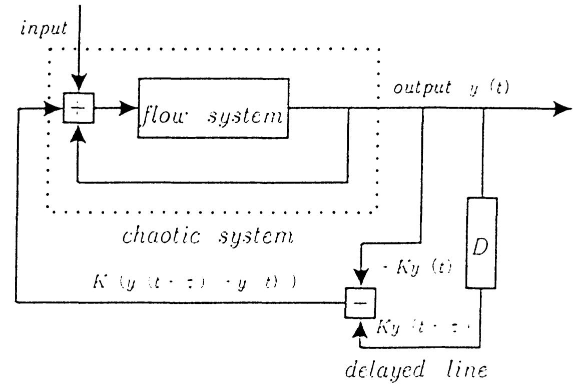

Figure 2. Block diagram of Pyragas' DFB control

EXPERIMENTAL RESULTS

As shown in Fig.3, The convection cell patterns caused by pulsed jets were labeled individually as R1,R2,R3 and R4 from left to right. For open loop control operation, the system is designed to be stable. That is, we see stable four convection cells driven by four constant velocity jets. However, in the case of closed loop operation, we see unstable oscillation due to improper feedback gain for simple proportional feedback control. Our objective is to stabilize the system by Pyragas' DFB control method. Fig.4 shows one example of successful implementation of the current method. Dotted lines depict flow states estimated by PIV or circulation of convection cells, which calculated along each stream line of cell. Pyragas' DFB control were turned on at 200 seconds after the moment unstable oscillation starts. As shown in Fig.4, amplitude of flow states became smaller after the control ON. And, deviation amplitude of control input(solid line in Fig.4), which is deviation value of actuator input, also smaller after the control ON. Although the flow states could not be perfectly stabilized to target reference value, we confirmed that deviations of flow states and control inputs for all four regions, namely R1 to R4, are decreased after Pyragas' DFB applied. We concluded that Pyragas' DFB method is effective for actual active flow control system, which can not avoid feedback lag time

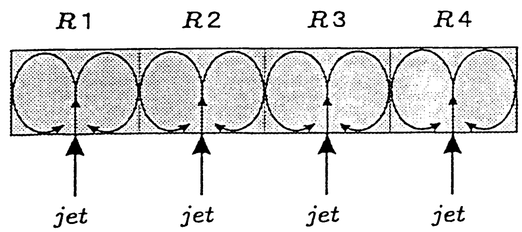

Figure 3. Four conviction cells are labeled as R1 to R4

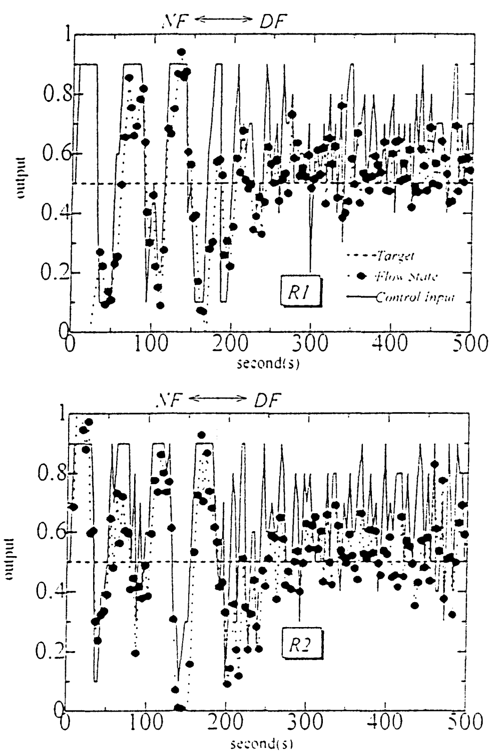

Figure 4. Experimental results for R1 and R2

experiments with PIV, even if the feedback delay is not negligible. However, selecting the good value of delay τ and DFB gain is not easy because of noise caused by flow estimator(or PIV system). And, optimal values for Pyrags' DFB is no theoretically well stated. So, we resorted to numerical simulation for finding optimal values and effective ranges of parameters.

Finite Difference method was used to solve 2D vorticity - stream function. Numerical grid was 60x10, and first order upwinding was applied to convection term. Poisson equation for stream function was solved directly by *Matlab* .

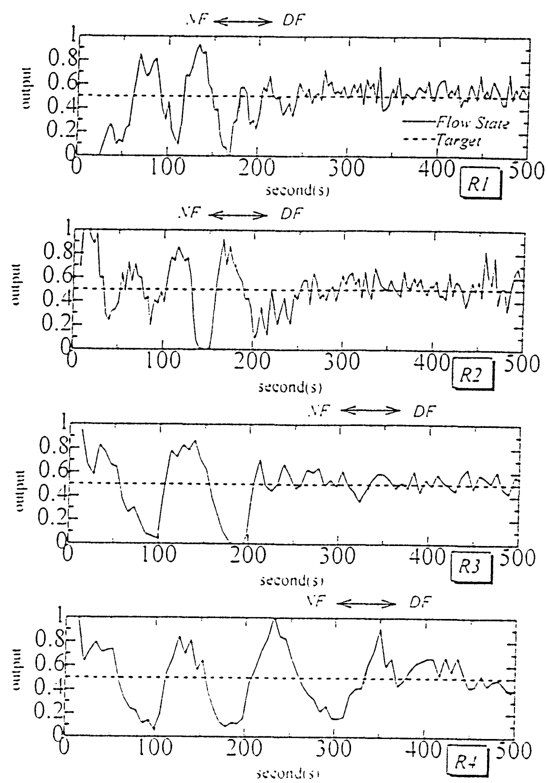

Figure 5. Numerical simulation results.

NUMERICAL SIMULATION AND OPTIMAL PARAMETERS

Numerical simulations were carried out to examine the current control method and to survey of optimal parameters. We checked that Pyragas' DFB method successfully selects a certain mode of flow pattern and makes the flow pattern stable by

Fig.5 shows a result for which the control started at 200 seconds after oscillation begun for region R1 and R2, and the same control started at 330 seconds. We see the flow states of R1, R2 and R3 are decreased soon after the control turned ON for R1 and R2. In other words, R3 region was stabilized when adjacent R2 was controlled. But R4 was continued to be unstable until R4 was controlled directly by its own Pyragas' control units.

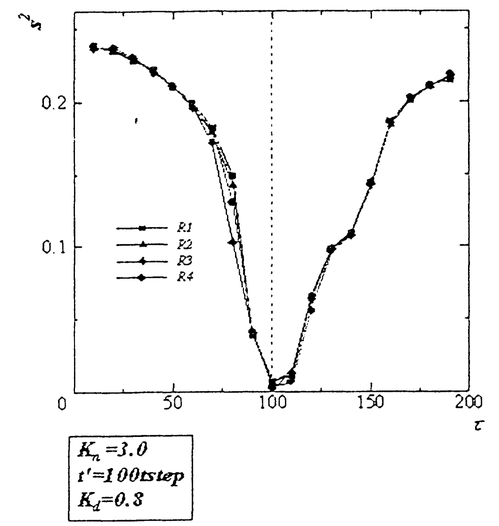

Figure 6. Cost function with respect to τ

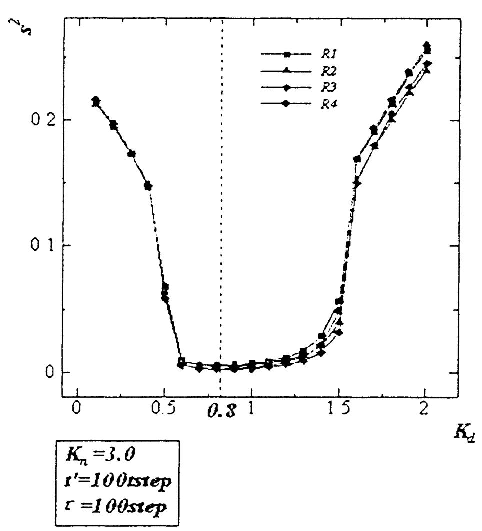

figure 7. Cost function with respect to DFB gain

The control results were summarized and examined by cost function S^2, which is defined as summation of flow state deviation and control input deviation.

Fig.6 depicts how cost function varies with respect to delay time τ. We clearly see the optimal value exists around 100 seconds. The optimal value does not seems to change for all four cells. And, we found that this optimal value roughly equals to the artificial time delay, which is introduced to cause instability. This implies that the optimal delay time for Pyrags' DFB is equal to lag time of the feedback control system used for the flow control. And, we found that multiples of this lag time tend to have local minima of cost function.

Fig.7 shows how cost function changes with respect to Pyragas' DFB gain. There exists optimal range of the gain value, but effecive range is rather broad when it is compared to effects of delay time.

CONCLUSIONS

Experiments showed that the present control method works reasonably well even for the system which has state estimation noise caused by PIV error and has non-negligible lag time in feedback system.

Parameter survey by Numerical simulations proved that optimal values of delay time and DFB gain exist. And, lag time of the feedback system seems to be an optimal value for the present Pyragas' DFB cotrol method.

REFERENCES

Kapitaniak,T, "Controlling Chaos,1996," Academic Press

Ogawara,K. and Iida,S.,1998, "Chaos Prevention for Flow Field feedback Control," Journal of JSME, Vol.65, No.629, pp.44-47

Iida,S., Ogawara,K. and Furusawa,S., 1996, "A Study o Bifurcation Control Using Pattern Recognition of Thermal Convection," JSME Int. Journal, Ser.B, Vol.39, No.4, pp.762-767

Iida,S.,Ogawara,K. and Takezawa,S.,1998, "Numerical Simulation of Jets Emitted into a Two-Dimensional Channel with Self-Induced Oscillation(Active Control by Neural network Observer)," JSME Int. Journal, Ser.B, Vol.41, No.4, pp.840-846