AN INVESTIGATION OF SIMULATORS OF AIR-REACTION ON RUDDER ACTUATORS

Zhao Lei, Yang Shuxing

Mechatronic Engineering Dept

Beijing Institute of Technology ,100081 Beijing

zh.lei.bit@263.net

ABSTRACT

This paper results from an investigation of the strategies of electro-hydraulic servo loading simulators. The purpose of the investigation is to get some helpful information for designing a new loading complex, which will be used to test a class of rudder actuators of flying objects. During the test, the loading complex is in charge of applying a varying torque, by means of electro-hydraulic servo, to an actuator oscillating in its own rule. This control is typically non-linear, time-variant, load-variant and with fierce position disturbances, rapid response and precise loading are its essential requirements. Experience shows it is very technically challenging to engineers and researchers. More than 100 articles, domestic or international, have presented a variety of approaches of improving control accuracy and stability of many servo loading realizations, some of them concentrate on hardware construction and some on control algorithms ranging from conventional PID, poles and zeros assignment to adaptive control as well as intelligent implementations. The focus of this paper is on strategies, limitations and needed efforts.

INDEX WORDS

electro-hydraulic, servo, loading, actuator, simulator

INTRODUCTION

A flying object can change its attitude and direction by adjusting rudder's angular displacement. When to change flying direction, commander sends instructions to rudder's actuator, then actuator drives the rudder toward its desired position. It is obviously the actuator plays an indispensable role in flying control, it must work well firstly to ensure a reliable flying. As the working conditions during flying are quite different from the ones at ground, how could we know it will be well during the flying before launching?

The investigated electro-hydraulic servo loading simulators are for the purpose of testing actuators on ground. In the test, when an actuator is driving its rigid shaft to rotate in its own rule, the loading system must apply a forward or backward torque to the actuator's output shaft. This torque should be an equivalent of the torque caused by air reaction on rudder's surface. It is roughly a function of time and angular displacement. But due to the rotation of the shaft or position disturbances, it is required that simulator have to perform a combination of two different functions simultaneously, one is to follow strictly the shaft's movement, and another is to yield a precise torque to the shaft. On the other hand, because of the uncertainty of shaft rotation, the simulator can't predict where the next position will be, this causes an absolute delay in following. Experimental results show that all these factors construct a tough challenge to all existing loading systems. When the shaft's rotating speed is slow, it is viable. But when the shaft rotates fast, the extraneous torque caused by hydraulic flow makes it very difficult to meet precision requirement.

To reduce the extraneous torque, many engineers and researchers have tried a wide variety of approaches and have achieved significantly toward perfection. But there are still many problems remaining. In the past year, through an investigation of several existing simulators and more than 100 related articles, we finished this brief summary of their specifications and limitations.

SPECIFICATIONS OF SIX SIMULATORS

The first one was produced in 1990, it is an electro-hydraulic servo system of four channels. Each channel of this simulator employs an electro-hydraulic flow control servo valve, a torque transducer, an angular velocity transducer, an angular displacement transducer and a hydraulic rotary motor. The shaft of the motor is connected firmly to the in-testing-actuator's shaft.

The main specifications of each channel are:

Maximum torque: ±250 Nm.

Maximum angular displacement: ±45 deg

Rotary moment: 0.25 $Kg.m^2$

Frequency bandwidth under non-disturbance: 10Hz (with 10% phase shift).

Working pressure: 18 Mpa

Its servo valve is Model DYSF-3Q, rated flow capacity is 80 L/min, working pressure range is 4 – 21Mpa, the

dynamic response frequency is 60 Hz(-3dB).
Its rotary motor's rated volumetric displacement is 18 cm^3/rad, rated working pressure is 21 Mpa, maximum output torque is 380 N.m.
The second simulator was made in 1998, the difference is it uses a twin-hydraulic motor to reduce extraneous torque. Its inner motor is for applying torque to rudder's shaft, the outer motor is for position synchronizing compensation. That is, the outer motor follows the movement of a rudder shaft, the inner motor keeps motionless with respect to the outer. Its electro-hydraulic servo valve is FF108 with 60 l/min rated flow capacitor and 250Hz(-3dB) frequency bandwidth. The specifications of this simulator are :

Maximum torque: ±400 N.m.
Maximum angular displacement: ±45 deg.
Maximum angular velocity: 400 deg/s.
Static loading precision: 0.5%
Frequency bandwidth: 10 Hz(with 10 deg phase shift)
The specifications of No.3 , No.4, No.5, and No.6 are:

1. Maximum torque(N.m): 464, 137, 200, 250.
2. Maximum angular displacement(deg):
   ±45, ±45, ±40, ±40.
3. Maximum angular velocity(deg/s):
   (No.3)600, (No.4)700, .
4. Torque resolution(N.m): (No.3)1.16, (No.6)1.2
5. Static frequency bandwidth:
   (No.3)50Hz(-90 deg phase shift),
   (No.4)50 Hz(-90 deg phase shift, 34.3 N.m),
6. Dynamic frequency:
   (No.5)15 Hz(-3dB)(±2 deg sine movement),
   (No.6)9 Hz(10 deg phase shift)

Though these are specifications of only six simulators, they reflect the development of this field..

ANALYSIS OF HARDWARE STRUCTURE

As shown above, almost all loading simulators are electro-hydraulic servo system with servo valve and servo rotary motor , a rudder shaft is fixed on the rotary motor's shaft. To meet the loading accuracy, many means have been tried in hardware and in software, here are some means in hardware structures.

1.Using an under-lap flow control servo valve instead of zero or over lap servo valve.
2.Opening interconnected pores between two chambers of rotary motor.
3.Adding a small servo valve or restricting by-pass in parallel with the main servo valve to form a by-path
4.Choosing a power supply with high stable working pressure
5.Using a servo valve with high dynamic frequency.
6.Selecting a rotary motor with high working frequency and enough torque output.
7.Trying to decrease the rotary moment of the shaft with things mounted on it.
8.Designing twin-hydraulic synchro-compensation motor.

Among the above means, under-lap valve, interconnected pore and small by-path valve aim to provide a quick discharge path when the controlled hydraulic flow changes direction, this is experimentally proved conducive to improving hydraulic response, if not, the sharp change of flow direction will cause jam or damage to some components. The stable working pressure, high frequency valve and high response rotary motor are prerequisites to a fast response loading simulator. The twin-hydraulic synchro-compensation motor is a unique invention in eliminating position disturbances as described in above No.2 specifications.,

STRATEGIES OF CONTROL

Besides the optimal hardware structure in hydraulic complex, control strategies are becoming more and more important in a control system. With the development of control theory, many theoretical achievements have been implemented in different applications and been proved more effective. Truly, our investigation reflects the same trend at this point, more researchers are tending to try some new control algorithms and new circuits in their experiments or employ a mixture of new and traditional, rather than fixing only on all conventional methods. The following approaches are abstracted from the articles investigated.

1.Adding a feed forward compensator depending on structural invariance principle.
2.Adding state observers to form an optimal system.
3.To establish a multi-variable model of the simulator, depending on multi-variable control theory , to realize a multi-variable decoupling control.
4.Adding velocity feed back in closed loop control.
5.Using CMAC cellular network control.
6.Using comprehensive control strategies including constant compensation, sliding mode, robust and adaptive etc.
7.Using two-degree-of-freedom PID control.
8.Using variable structure control.

All of them have been experimentally studied, almost every one can contribute to the eliminating errors or to up-grading response frequency from some particular angles.

PROBLEMS REMAINING

The above specifications show that the dynamic frequencies are lower than 20Hz, and the maximum loading torque is lower than 600 N.m, the loading precision is poorer than 10%. But at present, some rudder actuators work at 30Hz or beyond, and some of them suffer an air reaction higher than 800N.m. As a simulator, its dynamic frequency bandwidth should be three times or more the rudder's frequency, obviously, 20

Hz is far from enough to meet test requirements (at least some of the tests). And the torque output is not yet large enough. To get a high system frequency, every part of the system must be capable of higher frequency, so, as the most critical section, the servo valve must have a 250 Hz frequency or higher with enough flow capacity, but it is hard to meet in the present market. And the rotary motor should have a 100 Hz frequency or higher with enough torque output and angular displacement, but this requirement looks beyond the availability of present manufacturers. Upon the above analysis, to make a satisfactory simulator, we should firstly make the needed servo valve and rotary motor. On the other hand, experimental results show that a higher working pressure is helpful to upgrading working frequency, but to raise working pressure and ensure no internal or external leakage, the quality of all parts of a hydraulic system must be good enough to withstand higher pressure. The present working pressure is about 21 Mpa or so, if it were 32 Mpa, a compacter simulator with higher frequency would come to us.

In the respect of control strategy, the complexity of the simulator makes it difficult to acquire an exact mathematical model, to make the situation much worse is its inherent hysteresis and its passively following and loading mode. It is an unprecedented task in electro-hydraulic control, the further study of its characteristics and new control approaches are needed.

CONCLUSIONS

Upon the above analysis, we can get the following conclusions. Air-reaction simulator is a complex system involving mechanical, electronic, hydraulic, control, computer technology. To achieve a higher dynamic frequency and loading precision, the further efforts should be directed toward experiments and researches of higher pressure hydraulic elements, fast response servo valve with higher flow capacity, high working pressure rotary motor with higher dynamic frequency. And at the same time, more efforts should be concentrated on research of novel control strategies.

REFERENCES

[1] Jae Gyu Lee, Development of a new hydraulic servo cylinder with mechanical feedback, Control Engineering Practice, 7 (1999) 327-334.

[2] Jihong Wang, Accurate position control of servo pneumatic actuator systems: an application to food packaging. Control Engineering Practice, 7 (1999) 699-706

[3] Junsheng Pu, A practical control strategy for servo-pneumatic actuator systems, Control Engineering Practice 7 (1999) 1483-1488

[4] Ravi N. Banavar, A loop transfer recovery approach to the control of an electro-hydraulic actuator, Control Engineering Practice 6 (1998) 837-845

[5] Yong-Soo Jeon, Optimization o the control parameters of a pneumatic servo cylinder drive using genetic algorithms, Control Engineering Practice 6 (1998) 847-853

[6] Garett A. Sohl, Experiments and Simulations on the Nonlinear Control of a Hydraulic Servo-system, Vol7, No.2 March 1999,IEEE Transactions on Controls Systems Technology,

[7] M-H Chiang, Adaptive servo-control for hydraulic excavators, PTMC'98

[8] KAHN, SYOKOTA, Application of an impedance-force control to a six-link electro-hydraulic manipulator, PTMC'98

[9] KARAKI, YB YIN, Hardware approaches for a pneumatic force control system with an asymmetric servo valve of a spot welding machine, PTMC'98

[10] M BELGHARBI, Force tracking control of an electro-pneumatic actuator using a linearized model around the reference trajectory, PTMC'98

[11] P E HANSEN, Adaptive non-linear control of hydraulic actuator systems, PTMC'98

[12] D V LAZIC, Practical tracking of a hydraulic cylinder and axial piston hydraulic motor, PTMC'98

[13] R GUENTHER, Experimental implementation of the variable structure adaptive cascade control for hydraulic actuators, PTMC'98

[14] H HANDROOS, Sliding mode control of a hydraulic position servo with different kinks of loads, PTMC'98

[15] Z B RIBAR, Practical tracking control of electro-pneumatic piston drive,PTMC'98

[16] W.BERNZEN95, nonlinear control of hydraulic cylinders- theoretical and experimental results,PTMC'98