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THE TECHNOLOGY TREND AND PERSPECTIVE OF HYDRAULICS IN AIRCRAFT FLIGHT CONTROLS

Hirokazu YOSHIDA*, and Shinya SATO**

* Preliminary Designing Section, Defense Aircraft Engineering Department
Mitsubishi Heavy Industry, Nagoya Aerospace Systems
10 Oye-cho, Minato-ku, Nagoya 455-8515 Japan
(E-mail: hirokazu_yoshida@mhi.co.jp)
** Mechanical Systems Designing Section, Defense Aircraft Engineering Department
Mitsubishi Heavy Industry, Nagoya Aerospace Systems
10 Oye-cho, Minato-ku, Nagoya 455-8515 Japan

ABSTRACT

The recent technologies of hydraulics and flight controls have been progressing step by step. The research effort for establishing the technology to build 55.2MPa (8000psi) hydraulic system for practical use has begun to fruit around the world, and high-pressurizing is getting to be standardized, shifting from the conventional 20.7MPa (3000psi) system pressure. The system pressure is settling into 34.5MPa (5000psi), which is practical in both cost and performance with the appropriation of the existing parts and ground support equipment considered.
Also, ALL ELECTRIC AIRCRAFT (AEA) technologies proposed more than 20 years ago have begun to come into practical use, such as electric actuators for primary control surfaces, as improved are 270Vdc power source technology, the permanent magnet peformance for electric motors, the power transister capability for control device, and the reliabilities of mechanical parts such as ballscrews and bearings.
This paper discusses the application of new materials to aircraft such as piezoelectric, magnetostrictive, and shape-memory materials, which have recently become stabilized in production and begun to be applied in commercial fields other than aircraft industry.

KEY WORDS

Aircraft, Hydraulics, Actuator, Active, Material

INTRODUCTION

Aircraft have two kinds of power generation systems, “Hydraulic” and “ Electrical,” to drive various subsystems on board. These two power generation systems are used in proper combination with system functions well distributed over them, which gives the optimum redundancy to system functions in aircraft to secure the flight safty.
Hydraulic systems are mainly used to drive flight control systems and landing gear systems in aircraft. These systems consist of servo-actuators, servo valves, solenoid valves, power cylinders, hydraulic motors, check valves, orifices, and they are not so different from industrial hydraulic systems in terms of hydraulic compositions.
Then, this paper summarizes the technology trend of aircraft hydraulic generation systems and flight control servo-actuators, and gives information on the application of new materials to Electro Hydraulic Servo Valves.

AIRCRAFT HYDRAULIC SYSTEM

Aircraft hydraulic system pressure had been 20.7MPa (3000psi) for a long time, but the system evaluation tests and flight tests of 55.2MPa (8000psi) hydraulic system has been started around 1970 with the developments and testing of hydraulic components for 55.2MPa (8000psi) system conducted simultaneously. Then, now hydraulic product makers are learning from those efforts and commercializing high-pressure aircraft hydraulic components. The large aircraft and high maneuverability aircraft lately under development are applying 34.5MPa (5000psi) hydraulic systems in many cases, and 34.5MPa (5000psi) is becoming the standard for aircraft hydraulic systems.

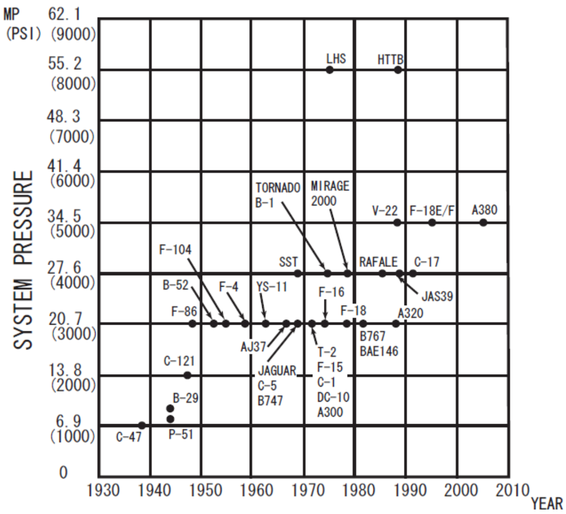

Figure 1 Hydraulic System Pressure Trend (Taki [1])

Some decades ago, mechanical signals from pilot commands were fed into manual valves to control flight control hydraulic servo-actuators. In around 1950, electrical computer controls became possible in aircraft controls, and since then, servo-actuators using Electrical Hydraulic Servo Valves (EHSV), which convert electrical signals into hydraulic signals which in turn amplify hydraulic power to control actuators, have been popular in aircraft flight controls.
Furthermore, since around 1990, direct drive valves (DDV), which use electric coil force motors to directly control main control valves, have been used as hydraulic servo valves, as electric magnets characteristics were improved. This DDV requires high cost to procure, and large aircraft still use EHSVs for servo-actuators, so the effort to reduce the production cost of DDV is required for the future.

HYDRAULIC AND ELECTRIC ACTUATORS

The system pressure becomes 34.5MPa (5000psi), and the reliability and maintenability of aircraft hydraulic systems have become quite stable. Also, aircraft electric power supply systems have been able to provide 270VDC power, and it has become possible to reduce the current in electric actuators and controllers by providing high-voltages in power supply systems. The production cost of electric actuators are getting low, and the reliability are being improved, as IPM (Interior Permanent Magnet) motor are started to be widely used such as in hybrid cars. As a result, replacing hydraulic actuators, electric actuators have started to be used in primary flight control systems in some new aircraft developments.
Table 1 shows the characteristics comparison between hydraulic and electric actuators.
As shown in Table 1, the performance of electric actuators matches for that of hydraulic actuators, so it is becoming possible to select two types of actuators according to power source redundancy (hydraulic and electric) and installation easiness of tubing or wiring.
However, electric actuators have to keep consuming electric current to hold an actuator position with aerodynamic load applied on when they are used in primary flight controls, while hydraulic actuators are capable of holding an actuator position against aerodynamic load with just control valve closed to maintain cylinder differential pressure. Also, hydraulic actuators are advantageous for flight control surfaces in that damping effect can be obtained in case of failures by utilizing bulk modulus of hydraulic fluid and flow restriction through orifices.
Sufficient considerations should be given to these characteristic differences and energy efficiency when hydraulic and electric actuators are applied.

Table 1 Characteristics Comparison Between Hydraulic and Electric Actuators

	Hydraulic	Electric
Speed	○	○
Frequency Response	○	○
Weight	unit:○ system:○	unit:△ system:○
Reliability	○ Leakage is the most frequent failure, but not as critical as piston sticking	△ Weight penalty of adding mechanism to prevent mechanical load paths from sticking
Maintenability	△ Frequent change due to leakage	○ Periodical lubrication required

NEW MATERILS TO HYDRAULICS

Flight control systems are now being high-pressurized and electricalized as above, and the electrical input (command) is converted to hydraulic command by motors or force motor.

Recently, researches for active materials, which convert electrical inputs directly into mechanical strokes, have been progressed. These active materials have mechanical strokes of about 10 to 100 micro meters, so they cannot simply replace hydraulic actuators which have mechanical strokes of about 10 to 100 milli meters. However, active materials are possible to be utilized as actuating devices in servo valves, shutoff valves, and very small hydraulic pumps.

Active materials such as piezoelectrics and electrostrictives respond well at high frequencies of the order of 1000Hz, and some efforts are being put into the researches to apply active materials to very small pumps and servo valves utilizing this characteristic. Also, shape-memory alloys can be applied to operate selector (on/off) valves for hydraulic components which do not require high response operations.

It is expected that these active materials are going to be applied to not only hydraulic components but also small moving products such as micro aircraft.

APPLIATION OF PEIZOELECTRIC STACKS

In this chapter, the application of piezoelectric stacks to electro-hydraulic servo valves (EHSV) generally used in aircraft hydraulics in large numbers is considered.

Figure 2 shows a typical EHSV. Coils (electric magnet) in the upper portion produce magnetic forces as currents are through them, and the force moves the flapper in the first stage. This flapper movement in turn changes pressures on both end of the valve spool in the second stage. In this way, control pressures are amplified in the second stage to move the main control valve of servo valve. The displacement of the flapper base produced by the electrical magnet is so small that it is possible to apply active materials to this part.

The reasons that piezoelectric stacks are selected for EHSV driving element from among several types of active materials such as magnetstrictives and shape-memory alloy are shown below.

(1) The frequency response of EHSV is 10 to 200 Hz.

(2) The electrical magnet part, which is the control portion of EHSV, is desired to be miniaturized.

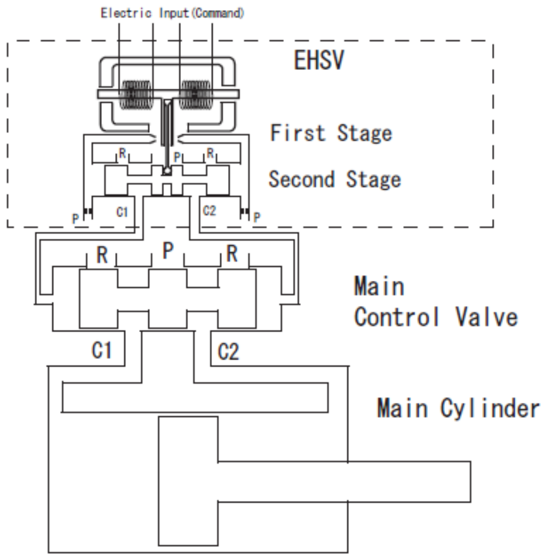

Figure 2 EHSV schematics

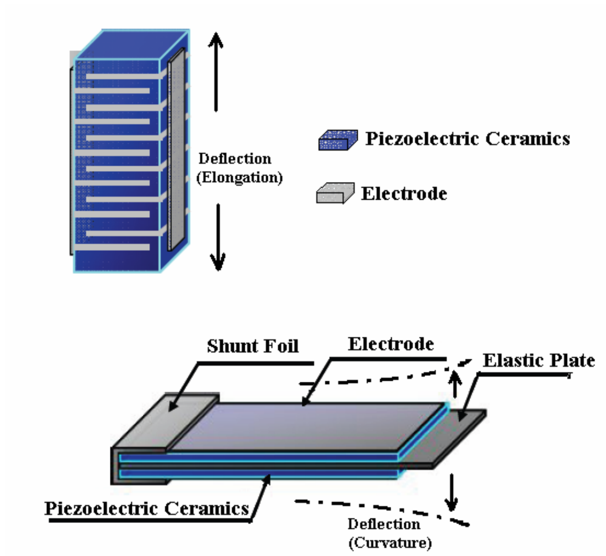

Figure 3 Piezoelectric Stacks(above) & Bimorph(below)

Also, although bimorph piezoelectric members can produce relatively large displacement, the generated force is not large enough to stably operate EHSV against hydraulic pressure fluctuation and flow forces. Thus, the stacked piezoelectric element type is selected, which is capable of producing both displacement and force enough for stable operations.

Table 2 Applicability of Active Materials to Servo Valves

	Piezoelectric	Megnetstrictives	Shape-memory	Electrical
Response	High	High	Low	High
Weight	Light	Heavy	Light	Very Heavy
Displacement	Small	Small	Large	Medium
Force	Large	Large	Small	Medium

Table 2 summarizes the applicability of active materials to servo valves.

Ref. 2. put together the experimental data collected for the stack piezoelectric element of 7mm by 7mm by 32mm size. The deflection is 30 to 50 micro-meters, which is enough for EHSV application.

Figure 4 shows that the Young's modulus to temperature is stable at -20 to 120 degree C. Since the usage temperature of EHSV in aircraft hydraulic system is from 0 to 80 degree C, the thermal compatibility will meet the requirement for practical uses. Also, the hysteresis characteristic shown in Figure 5 is as favorable as that of the electrical magnet is.

The piezoelectric stacks are vulnerable to tensile forces, and avulsion of stacks will be caused by tensile forces. Thus, it is required to be used with compressive forces pre-loaded. Conveniently, the deflection characteristic is little affected by compressive preload forces.

Therefore, it is possible to design with compressive preload forces so that piezoelectric stacks will have enough durability, and the design of the preload forces will have an impact on a product life. In conclusion, it is considered that the application of piezoelectric stacks to aircraft hydraulic EHSV will become practical by testing and evaluating power consumption, environmental condition requirement (vibration, high and low temperature, thermal shock, fluid compatibility,) and durability in the future.

POSTSCRIPT

The aircraft hydraulic system is making progresses step by step, and now, its reliability is well-established. It is required to make it more efficient, more reliable, and lighter in weight by studying the application of new materials in the future.

Also, The aircraft hydraulic and general industrial hydraulic systems are common in the base technology, so effort should be made to lower the system cost by making components tandardized as much as possible.

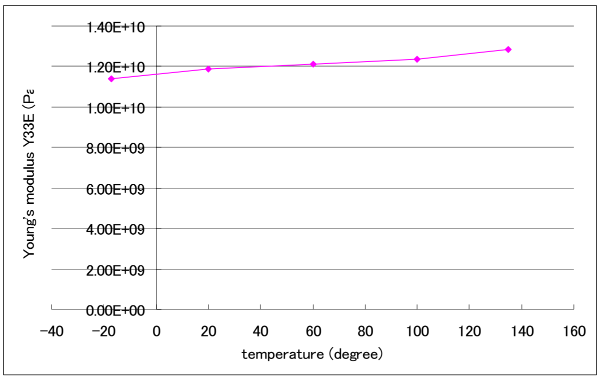

Figure 4 Young's modulus – temperature relationship of piezoelectric stacks (Tanaka [2])

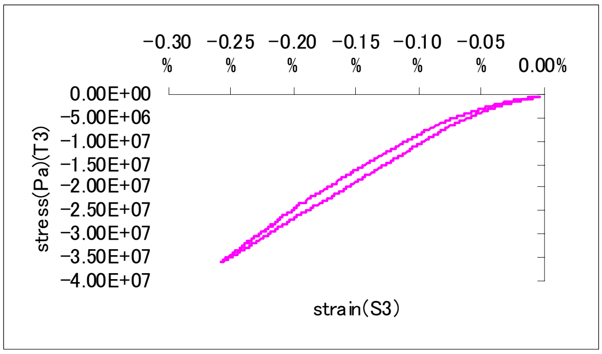

Figure 5 Hysteresis characteristic of piezoelectric stacks (Tanaka [2])

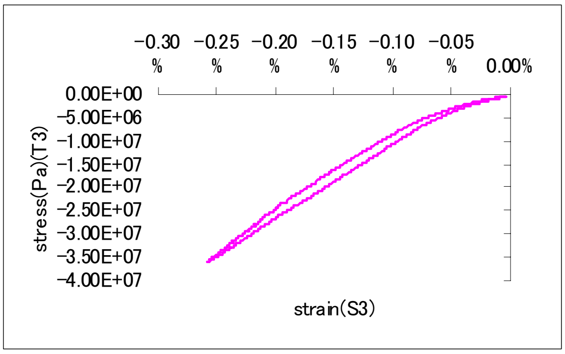

Figure 6 Displacement - compressive preloaded force relationship of piezoelectric stacks (Tanaka [2])

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