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Simulation and Effect of Hydraulic Actuator on Pilot Induced oscillation In Helicopter

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Abstract

Pilot induced oscillation (PIO) in helicopter is a random, low frequency pitching and heaving movement. It is a phenomenon wherein the amplitude of fuselage oscillations in the vertical direction at a specific frequency (4 to 5 Hz) becomes increasingly large with time. Mostly this tendency originates due to disturbing energy feedback into the main rotor through the control circuits. Pilot-induced oscillations have been an aviation problem for over 100 years now. A pilot induced oscillation is defined as "an inadvertent, sustained aircraft oscillation as a consequence of an abnormal joint enterprise between the aircraft and the pilot [1]". The control system connects the displacement of the controls to changes in the pitch of the main rotor blades using hydraulic actuator. Many factors like stick force, friction in circuit and actuator delay affect the PIO. Among many factors actuator delay plays an important role, phase delays will PIO prone. In this paper, hydraulic actuator is modeled by sub-dividing the Actuator system into various sub-elements, in the context of simulating and analyzing response characteristics towards PIO. The obtained results are analyzed and validated by comparing with the actual test data. The model is tested with different input frequency conditions.

1. Introduction

Pilot induced oscillation (PIO) in helicopter is a random, low frequency pitching and heaving movement. It is a phenomenon wherein the amplitude of fuselage oscillations in the vertical direction at a specific frequency (4 to 5 Hz) becomes increasingly large with time. PIO is not a voluntary thing, it is the interaction between vertical g force and the pilot's mass, as well as the damping on the collective. Pilot will acts as sort of mechanical impedance between dynamically and aero elastically induced vibrations of the body, and the resulting inputs that are inadvertently transferred to control system. The main thing to know about PIO is that it is an undesired movement of the helicopter which makes it oscillates and looses its stability. As the control system of the aircraft uses a closed loop, these oscillations are amplified then they become bigger and the aircraft stability is much worse. This PIO behavior appears through a variety of flight conditions and is very difficult to predict. Due to this complex behavior, PIO is not easily eliminated [2].

In other cases, the pilot can interact with an airframe harmonic, and again, this oscillation can be quickly divergent in nature. The frequency of these oscillations is usually in the 4-5 Hz range. The research activity dealing with the PIO phenomenon is not as advanced as in the fixed wing aircraft case and very few published papers analyzing this subject can be found in literature [3]. The available literature mainly focuses on the investigation of problems that directly involve an active participation of the pilot: the so-called Pilot-Induced Oscillations (PIO). PIOs occurs more frequently, although test pilots, flight test engineers and handling qualities specialists have dealt with this phenomenon over the past decades, still it is very difficult to apprehend and all too often it catches pilots as well as engineers by surprise[4].

1.1. Origin of PIO and effect of actuators

The helicopter begins a gentle vertical vibration at such a frequency as to "bounce" the pilot up and down in his seat. The vibration is initially quite gentle and but because the pilot is beginning to bounce, his left arm moves the collective slightly up and down at a resonant frequency and cyclic stick slightly forward and aft[5]-[6]. This makes the vibration worse, so the helicopter bounces harder and the pilot bounces more so his arm moves more and it implies on phase delays of actuator response and the phenomena will be divergent. A vibration along the vertical axis may cause the involuntary introduction of collective and cyclic (pitch) control input. As a consequence, the rotor flapping (cone) dynamics may be excited, eventually resulting in sustained vertical oscillations of the airframe [7]. The resulting oscillations may endanger the safe execution of a mission task and, unless stopped, cause severe damage to the vehicle, or even its loss.

1.2. About actuators

A Hydraulic Actuator is a device, which converts Hydraulic energy into Mechanical force or motion. Hydraulic Actuators have the ability to impart large forces at high speeds. These Actuators are used in Aerospace applications for controlling various flight surfaces and flight components. Actuators may be divided into those with linear movement (sometimes called rams, cylinders or jacks), and those with rotary movement (rotary actuators and motors)[8]. Linear actuators may be further sub-divided into those in which hydraulic pressure is applied to one side of the piston only (single acting) and are capable of movement only in one direction, and those in which pressure is applied to both sides of the Piston (double acting) and are therefore capable of controlled movement in both directions.

Linear actuators may also be classified as single-ended, in which the piston has an extension rod on one end only, or the double-ended type which have rods on both ends. Single-ended actuators are useful in space-constrained applications, but unequal areas on each side of the piston results in asymmetrical flow gain which can complicate the control problem. Double-ended actuators have the advantage that they naturally produce equal force and speed in both directions, and for this reason are sometimes called symmetric or synchronizing cylinders. Hydraulic motors are a separate class of actuator, in which the speed and direction of a rotating output shaft is regulated by the flow control valve.

2. Modeling of the actuator system

Modeling of a Hydraulic Actuator system is very useful in providing the information regarding the responsiveness of the system (output piston stroke) for the input given by the pilot when the rotor blade control is required to manoeuvre the rotor craft. The 'Model' provides data with respect to various loads from 'No load' to '13000N'.We can simulate the system function virtually at various external load conditions. The circuit is subdivided according to it's functionality as I. Mechanical mode. II. CSAS mode. As shown in figure 1. The difference between theses modes lies in the feedback control mechanism. Though both are controlled by closed loop control, the mechanism differs as mechanical mode uses linkages to bring back the spool to original position when the output piston reached the required position, while CSAS uses the Digital/Electronic control to monitor whether the piston achieved the required amount of displacement or not.

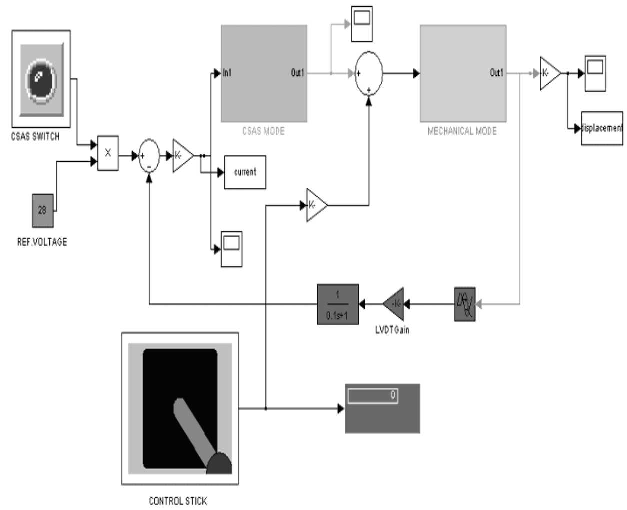

Fig.1 Hydraulic Actuator system model

In the model, the CSAS is controlled by the feedback voltage given by the LVDT gain block, which is taking input from the output of the piston. For CSAS mode this becomes the closed loop comprising the Mechanical Actuator block while the control stick is kept at 'zero' position. Consider the maximum stroke the CSAS is 12% (7.8mm) of the total stroke (assumed value 65mm) achieved by the Mechanical mode. If the pilot wants more movement the input should be given in multiple cycles that each cycle output accumulated and gives the desired output movement in CSAS mode of operation

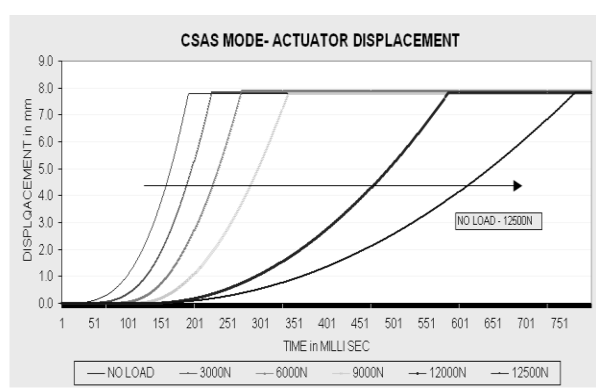

Fig.2 CSAS mode actuator displacement

In Mechanical mode operation, the inherent mechanical feedback control makes the LVDT –Digital control ineffective. The output piston, which is connected to the control valves and pilot control stick through linkages, moves and it automatically, reduces the control valve spool displacement. When the output

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piston reaches out the final point the control spool displacement becomes zero and the control valve port is closed and thus it is no more allowing the fluid to flow in i.e. it is no more connected to the system pressure line. Figure 2 and 3 shows actuator displacement with various loads in CSAS and mechanical mode.

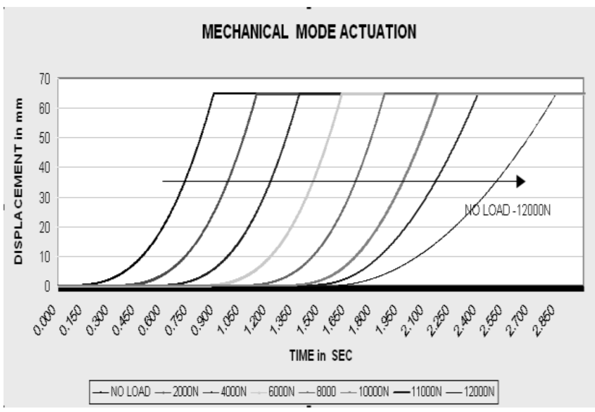

Fig.3 Mechanical mode actuator displacement

3. Modeling of hydraulic system

The approach in making a model of Helicopter hydraulic system is to be focusing of two parameters of Hydraulics. First one is Hydraulic pressure and the other is Hydraulic Flow. All components and sub systems are related to these two main parameters to yield the output (Displacement). Hydraulic pump creates oil to Flow. When the Flow of oil gets obstructed, i.e. there is no additional space to cater the increase of flow volume of oil, the volume of fluid flow generated exceeds the fixed confined volume, pressure is being developed. This pressure if it is exposed to a definite area of cross section, Force is being created. The output displacement is done because of the force, created. The whole system, sub systems & components are related in the following aspects: i) To maintain the System pressure in the desired, normal operating range. i.e. 206 ±6 bar. ii) To create Hydraulic oil flow, when the displacement of the Actuator is required and to stop the Oil flow, when the required displacement is achieved. iii) To remove the excess volume of hydraulic fluid, when the pressure reached the above predefined critical limit.

All these aspects are concerned while designing the virtual model. All the blocks, components & cub systems are modeled to have a valid input- output relationship. As the model grows up from the root level to the top level, the sane relationship becomes multi input & multi output system as shown in figure 4.

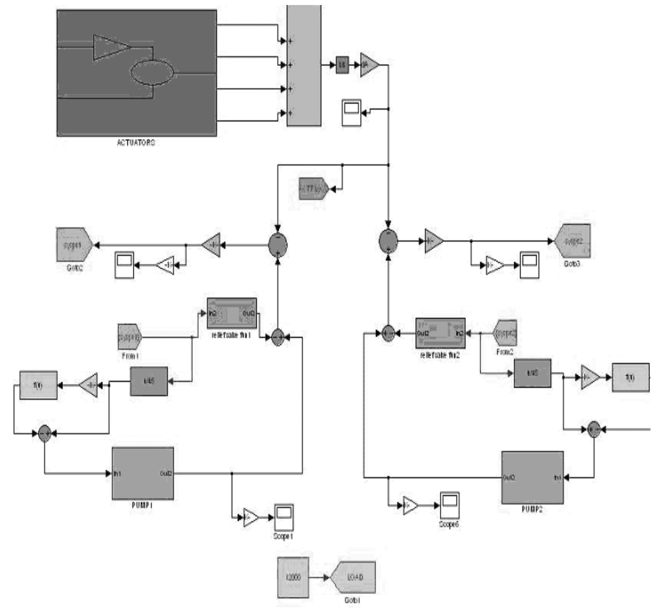

Fig.4 Hydraulic system model

4. Simulation Results and Conclusion

The integrated top level Hydraulic system Model is simulated using MATLAB 7.0 with simulink with following simulation parameters. Solver type: Fixed step, Solver method: Runge-Kutta and simulation mode: Normal

4.1 Actuator response for the control stick input for the load of 12000N

The simulation will be an exact type of Control stick movement being done by the pilots in real conditions in helicopters. The external load, mainly because of aerodynamic forces acting on the control surfaces, which actually experienced by the pilots while moving the control stick, will be varying from No load to 27000N, is depending upon the pitch angle of the rotor blades if both of the Hydraulic systems are working. Here a typical 12000 N load is considered.

Here the actuator control stick is moved from zero position to maximum displacement (65mm) in three steps and the reverse movement has in random manner with a jerk in the middle to check the quickness of the actuator response as shown in figure 5

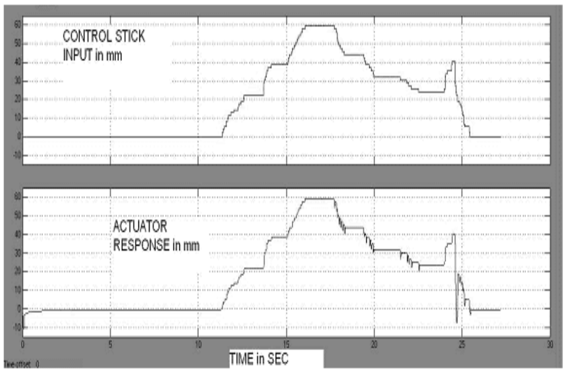

Fig.5. Actuator response for pilot I/P

It is found that the response time is 0.15 sec. 2. Whenever the control stick is moved in forward direction the response also in the similar manner as the input is varied. But when the control stick is reversed, the actuator is moving a little more than the input movement. This because of the external load (12000N) is acting in the same direction as the actuator piston moving direction. This creates an extra acceleration in the reverse direction. This extra acceleration will lead to phase delay and finally yields PIO.

4.2 Cyclic (sine wave) input for the frequency of 1 cycle /sec

To get the cyclic response of actuator a sine wave is introduced in place of control stick with the frequency of 1 cycle/sec and amplitude of 65mm. The response is shown in figure 6.

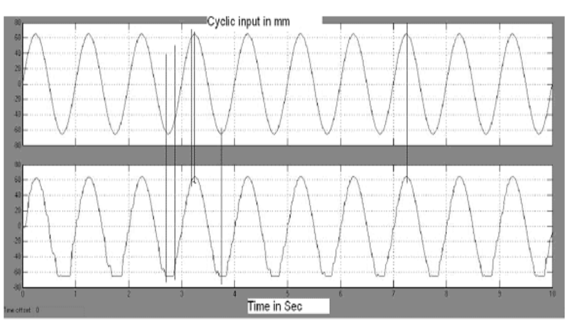

Fig.6 Actuator response for Cyclic I/P

From the above plot, it is evident that there is an initial time lag of 0.1 sec. And in the reverse direction the piston stays more time than the input peak, as the bottom portion of the curve is flat for the duration of 0.2 sec. But the overall cycle time for the response is same at the start& end of each cycle time. The lag at the bottom portion of the curve is compensated with steep rise in upward. Hence the cycle times of both the curves are same. This lag is measured as 1sec (maximum) and it implies on the induction of PIO on helicopter during flight.

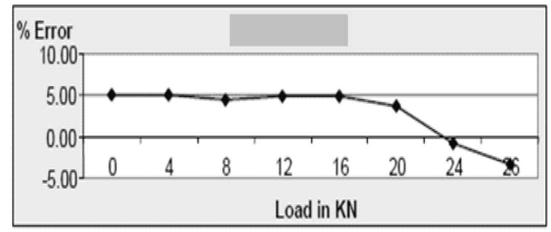

Fig: 7 Comparison of simulated data with experiment

To verify the results of simulation, the simulated results are compared with the real test data. The deviation between actual data and the simulated data is calculated and the percentage of error is calculated and shown in figure.7. From simulation and experimental data it is concluded that there is a phase delay in actuators and it plays important role in induction of PIO in helicopters.

5. References

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