Modeling and Investigation on a Jet Pipe Electrohydraulic Flow Control Servovalve

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Abstract The analyzed electrohydraulic servo valve is jet pipe type, is one of the mechatronics component used for precision flow control application. It consists of several precision and delicate components. For the analysis the jet pipe assembly of servovalve is identified and conducted a direct-solution steady-state dynamic analysis to study the response of the system for harmonic excitation. The flexure tube is one of the delicate and critical components in jet pipe assembly; the analysis was sighted around the flexure tube design and material property. The assembly was subjected for analysis to ascertain the response of the system for critical parameters like thickness of flexure tube and material for flexure tube. The system resonance frequency was observed for different flexure tube thickness and for different material properties of flexure tube.
Key words: flexure tube, resonance, jet pipe, steady state dynamics, flow control.

1. INTRODUCTION

Jet pipe electrohydraulic servovalve finds main application in actuating feedback control systems working on jet engine and fighter aircrafts. The primary flight control system for an aircraft is control-by-wire (CBW) and redundant digital processors are used to accept inputs from the cockpit controls and motion sensors and compute commands to the electrohydraulic actuators. Even though the leakage flow of the jet pipe amplifier is high compared to that of a flapper-type electrohydraulic servovalve, due to its capability of working in high-contaminated environment, it finds current application in fighter aircrafts. Jet pipe servo valves have one movable nozzle and two collector ports, from were fluid is ducted to the main valve spool. Pressure and flow in the collector ports are calculated from the principles of hydraulics, including a momentum balance. Thoma [1] has explained bond graph TUTSIM modelling approach, which is used to simulate the pressure in the receiver holes of the jet pipe servovalve. Dushes [2] has explained a pressure recovery in receiver holes of jet pipe servovalve, which is a function of jet pipe displacement relative to receiver plate. There are various parameters affecting the pressure recovery in the receiver holes. The major parameters are distance between the receiver holes (web thickness), jet pipe nozzle diameter, receiver hole diameters, jet pipe nozzle offset and jet pipe nozzle stand-of distance which are well explained [3].Henry [4] has presented an analytical and experimental investigation of a jet pipe controlled electro pneumatic actuator for frequency response and time-domain force tracking. The intent of this paper is to present the response of the electrohydraulic servovalve component like jet pipe assembly for harmonic excitation.

2. JET PIPE SERVOVALVE

A schematic representation of a jet pipe electrohydraulic servovalve is shown in Figure 1. The servovalve consists of two main assemblies, a torque motor assembly representing the first stage and the valve assembly representing the second stage. In-between the first and the second stages, there is a mechanical feedback connected to the spool and jet pipe to stabilize the valve operation. The jet pipe serves to convert pressure energy of the fluid into the kinetic energy of a jet and directs this jet towards the receiver block where its kinetic energy is recovered in the form of pressure energy. The valve operates as follows:

- At first stage null, the jet is directed exactly between the two receivers, making the pressures on both sides of the spool equal. The force balance created by equal pressures in both end chambers holds the spool in a stationary position.

- The first stage torque motor receives an electrical signal applied as current to the coils, and is converted into a mechanical torque on armature and jet pipe assembly.
- As the jet pipe and armature rotate around the pivot point of thin walled flexure tube, the fluid jet is directed to one of the two receiver holes in the receiver block, creating a higher pressure in the spool end chamber connected to that receiver. The differential pressure pushes the spool in opposite direction to the jet pipe displacement.
- As the spool starts moving, it pushes the feedback spring, creating the torque on the jet pipe to bring it back to null position. When the restoring torque due to spool movement equals the applied torque on the armature, the spool will stop in a particular position, until reversing the polarity of the applied current. This torque balance is said to be steady state operation of the servo valve. The resulting spool position opens a specified flow passage at the ports of the second stage of the valve.

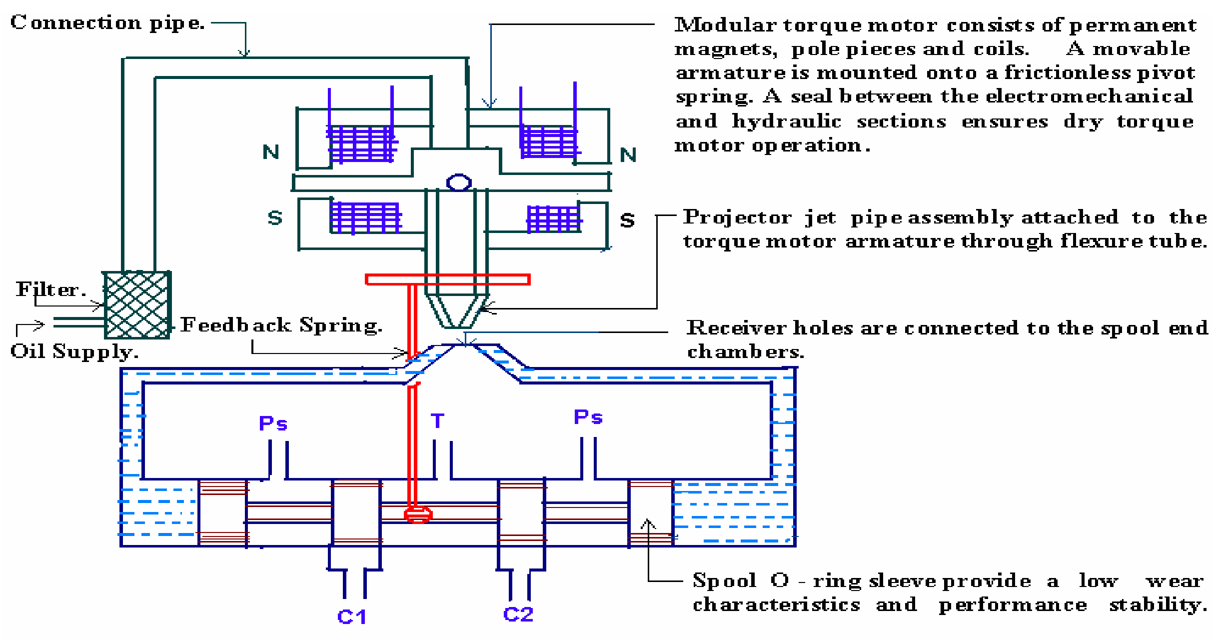

Fig.1 Schematic view of jet pipe servovalve.

3. DIRECT-SOLUTION STEADY –STATE DYNAMIC ANALYSIS

A direct-solution steady-state dynamic analysis is a linear perturbation procedure, used to calculate a system's linearized response to harmonic excitation. The solid model of the jet pipe servovalve is prerequisite for the analysis and was done using SDRC Ideas Ver. 7. With suitable boundary and loading condition, finite element analysis was carried out in Abaqus ver. 6.3. Fig.2 shows the solid and finite element model of jet pipe assembly, which consists of armature, armature bush, flexure tube, jet pipe, nozzle and oil supplying pipes. Depending upon the nature of operation, suitable elements are used in finite element with suitable material properties. The concentrated loads of 0.9414 N were applied on the armature, to create the torque on armature to rotate the jet pipe. These loads are sinusoidal with time over a user-specified range of frequencies. The jet pipe response was studied and was in Fig. 3, the jet pipe approaches the resonance frequency at 376.5 Hz with jet pipe maximum deflection as 1.6 E-01 m. These results were for flexure tube thickness of 45 micron and beryllium copper UNS 17300.

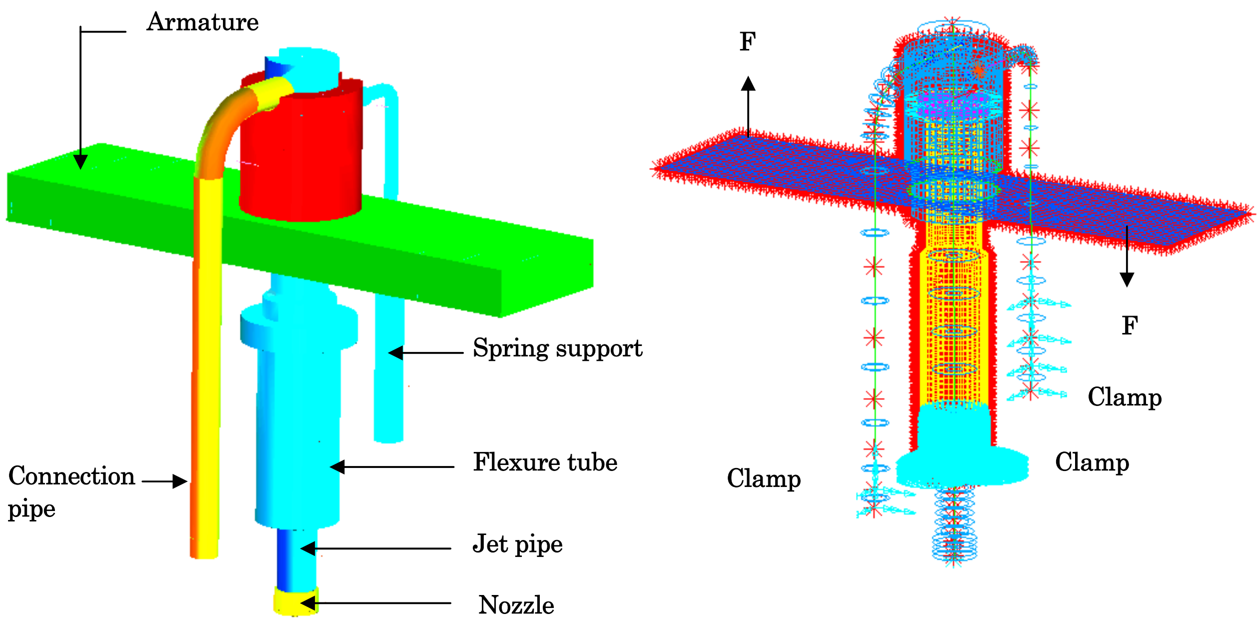

Fig.2 Solid and finite element model of jet pipe assembly

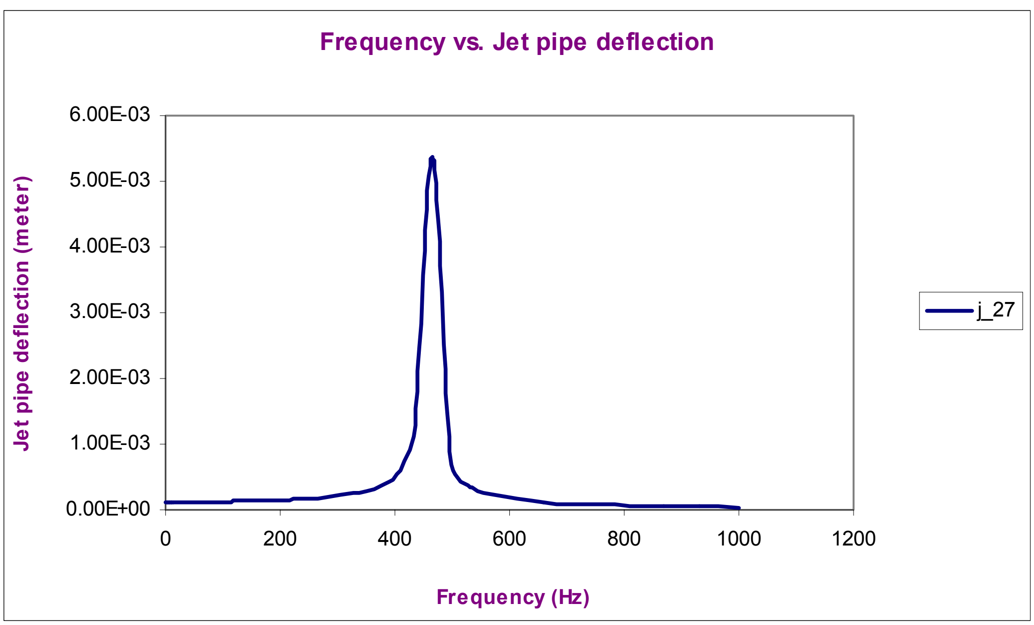

Fig.3 Jet pipe deflection vs. frequency

The analysis was extended to study the effect of flexure tube thickness and different material for flexure tube on natural frequency of the system and the obtained results were presented in Table 1.and Table 2. The natural frequency of the system was increases with increasing thickness and material property of flexure tube was dominant parameter, which should be considered during the design of precision flexure tube.

Table 1: Frequency response of jet pipe assembly (Flexure tube material: UNS 17300)

t_flex (µm)	F_arm (N)	δarm (m)	δjet (m)	Resonance (Hz)
45	0.9414	9.389E-02	1.600E-01	376.5
50	0.9414	7.333E-03	1.245E-02	403.7
75	0.9414	8.555E-04	1.433E-03	533.7
100	0.9414	1.824E-03	2.999E-03	613.6

Table 2: Frequency response of jet pipe assembly (Flexure tube material : AISI 316)

t_flex (µm)	F_arm (N)	δarm (m)	δjet (m)	Resonance (Hz)
45	0.9414	3.164E-03	5.374E-03	464.2
50	0.9414	2.203E-03	3.732E-03	497.7
75	0.9414	6.403E-04	1.073E-03	657.9
100	0.9414	6.664E-04	1.092E-03	756.5

4. CONCLUSIONS

The flexure tube is one of the critical components in jet pipe assembly. The steady state dynamic analysis was conducted on jet pipe assembly and studied the response of the system. The critical parameters like thickness and material of flexure tube was studied for the frequency response.

5. REFERENCES

1. Thoma, JU. Fluid mechanics, bond graphs a jet pipe servo valves, modeling and simulation of systems .IMACS, p. 77-81
2. Dushkes SZ, Cahn SL. Analysis of some hydraulic components used in regulators and servo mechanisms. Transactions of the ASME, May 1952. p. 595-601.
3. Somashekhar SH, Singaperumal M, Krishnakumar R. Design and Optimization of Parameters Affecting to Static Recovery Pressure in Two Stage Jet Pipe Servovalve. ASME Conference, ESDA 2002, paper No. ESDA2002/DES-020.
4. Henri PD, Hollerbach JM, Nahvi A. An analytical and experimental investigation of a jet pipe controlled electro pneumatic actuator. IEEE Transactions on robotics and automation. Vol. 14, No. 6, 1998, p.601-610.