

# **Non-linear flow control valve for Precision Positioning of Weapon System**

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## **Summary**

High inertia weapon system requires precise fine laying for accurate positioning of gun in addition to continuous target tracking and high speed maneuverability requirements. This paper describes in detail the selection of special port configuration in control handle valve considering specific requirements without compromising the resolution in the complete operating range. The options of various port configurations and its influence on valve area gradients is discussed. The flow achieved in the experimental setup is compared with theoretical calculations. It is also essential that the pressure drop across the valve to be minimum to avoid the jerky movement of load at smaller inputs. This paper explains development of above valve and its integration in weapon control system thus achieving the desired performance.

## **Keywords**

Spool sleeve valve, port, flow control, pressure gain.

## **1. Introduction**

Armoured Fighting Vehicles are provided with Weapon system of high inertia and large size. Hydraulic systems are preferred for these applications considering higher stiffness and smaller size drives. These systems are required to be moved at very fine laying speeds for accurate positioning and at high slewing speeds for quick engagement of targets. The speed range from minimum to maximum speeds is of very high order in the range of 1:4000. It is easier to obtain these speed ranges by using servo valves and by using the electronics to control the movement of spool. However, redundancy modes of the system demand manual back up through joystick of crew by appropriately controlling the flow. The friction in the drives and the large bearings are required to be overcome without causing any jerky motion during fine laying. It is essential to overcome this by proper shaping of spools and minimizing the pressure drop across the valve. These factors demand special shaped ports in the valve sleeves to achieve desired results.

## 2. Selection of Valve and Port Configuration

The key parameters in the selection of valve are the number of ways flow can enter and leave the valve, the number of lands and the type of centre when the valve spool is in neutral position. A four-way valve is the most acceptable choice, with two lines connected to the load and the two lines to pressure and return lines on supply side. Statically balanced four-land valve is the best option for this application with lands on both ends were extend to prevent leakage. A near zero over lapped or critical centered valve is chosen for better control close to dead zone. Fig. 1 shows the configuration of flow control valve selected for this application.

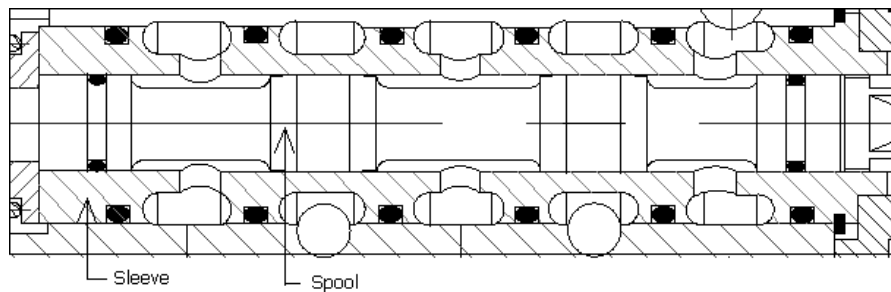


Fig.1 Cross section of Control Handle Spool-sleeve valve

The valve chosen for this purpose has to control a hydraulic cylinder in one axis and hydraulic motor in another axis. Considering the fine laying speed and maximum slewing speed requirements of the weapon the flow to actuator is to be controlled from 13 cc/min to 48 lpm, through this valve. The shape of the ports plays a vital role in deciding the flow pattern required through out the operation range. The principal requirements for the port design are:

- To precisely control the flow at very low speeds
- To provide required flow at maximum speeds
- To provide better resolution through out the operation range
- To Provide smooth start / stop conditions and to avoid hammering action
- To limit the pressure drop across valve and to have high pressure gain
- To avoid pressure ripples

Fig. 2 shows the flow gain characteristics of various port shapes used in the valve. Generally available flow control valves use either circular or rectangular port configurations. Circular shaped ports are easier to manufacture but does not provide required control on the flow requirements. A rectangular port provides linear flow response, but does not provide good resolution at low speeds. A

triangular shaped port provides non-linear flow with spool displacement. Limiting the angle at the apex, the low speed requirements can be met, but requires very long stroke to meet the maximum speed requirements. A port configuration with combination of two triangles is considered as best option that can meet the requirements of both low speed requirements and maximum flow considerations. The valve area gradient can be adjusted by adjusting apex angles of two triangles to achieve required flow characteristics.

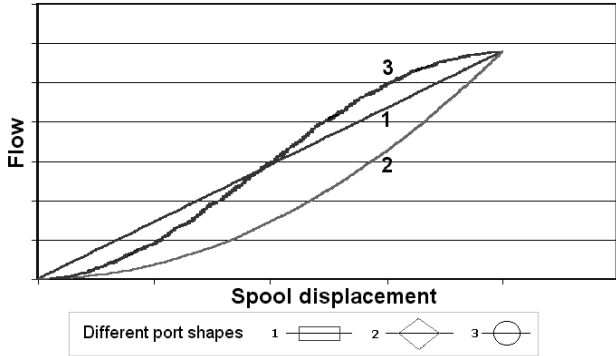


Fig. 2 Flow Characteristics of different port shapes

**3. Design Considerations**

By considering a 2-step non-linearity and practical requirements, half the spool travel is considered for low speed area and remaining half for the high speed zone. The expected flow pattern and the port shape are shown in figs. 3 & 4. The manufacturing process of this configuration involves electro-discharge machining and difficult to maintain the dimensions especially at the tip of the small triangle due to tool wear. It is also difficult to precisely estimate the flow coefficients at the tip of the triangle. Problems of non-uniform movement of the drives are expected at the transition zones, when the spool moves from smaller triangle area to bigger one. The sharp starting edges of triangle also pose problems in clearly defining the ends for critical center valves, which results in excessive leakage at dead zones or null position.

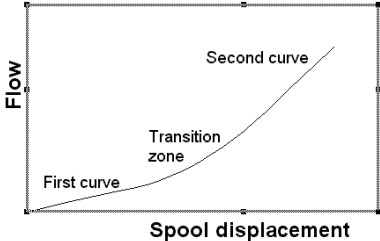


Fig. 3 Flow Characteristics

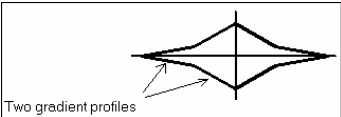


Fig. 4 Two triangle port

The deficiencies in the above design can be corrected by limiting the triangular profile only in high flow zone and altering the design for low speed requirements. Instead of altering the opening in the port shape of the sleeve, a taper of a very small angle was introduced in the spool land partly. The effect of this taper was similar to the small triangle in the port shape of sleeve. With this, the design of port also becomes simpler and both sleeve and spool can be manufactured easily. Fig. 5 & 6 modified views of the spool land and port shape in sleeve respectively. Fig. 7 indicates the combined spool and sleeve at null position. The dimensions of spool size and area of opening are decided on the flow requirement.



Fig. 5 Modified spool land

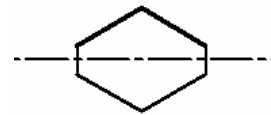


Fig. 6 Modified port

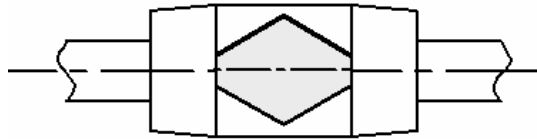


Fig. 7 Spool-sleeve at Null position

The angle on the spool is decided on the gradient required at fine laying speeds. Fig. 8 shows the effect of angles from 1 to 10 degrees of spool angles. It can be seen that smaller angles give fine control over minimum speed. Spool with 2 degrees taper was considered as best option to meet the given specification of minimum speed.

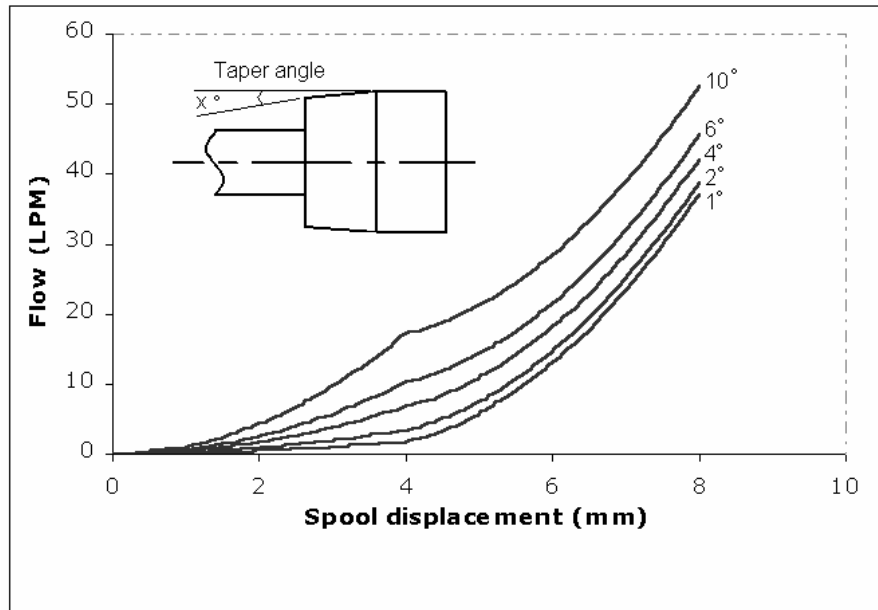


Fig. 8 Flow vs. Spool displacement for different taper angles

#### 4. Analysis of Test Results

The spool-sleeve combination was installed in valve housing and appropriately connected to supply lines and control ports. The spool was connected to ergonomically designed hand grips to control the drives. The spool position was brought to neutral position in off condition by providing springs in the axis of spool. The valve was tested on hydraulic test bench at 100 bar pressure and flow gain was measured at different positions of the spool. Displacement of spool was fine controlled with the special tool made for testing purpose. Fig. 9 shows flow vs. displacement at different positions of spool.

The test results are plotted in comparison with hydraulic flow calculated theoretically. The variation with respect to theoretical calculations is due to the approximate flow coefficient assumption. It can be seen from the plots that the output flow is very smooth over the entire operation range, with no sudden jump at the transition phase.

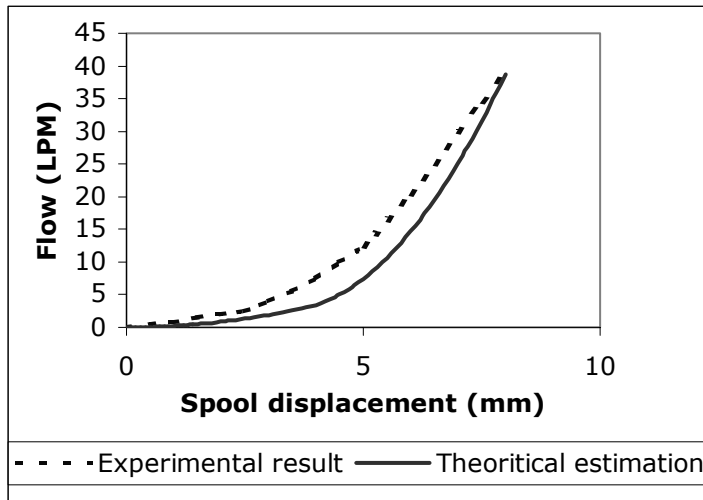


Fig. 9 Flow vs. Spool displacement @ 100 bar

With appropriate test set up, the pressure gain near neutral position was measured. The experimental results were shown in fig. 10. It has been found that the control port pressure reached 60% of supply pressure at .02 mm movement of the spool (0.25 % of full stroke) and 100% within 0.2 mm movement of the spool (2.5 % of full stroke).

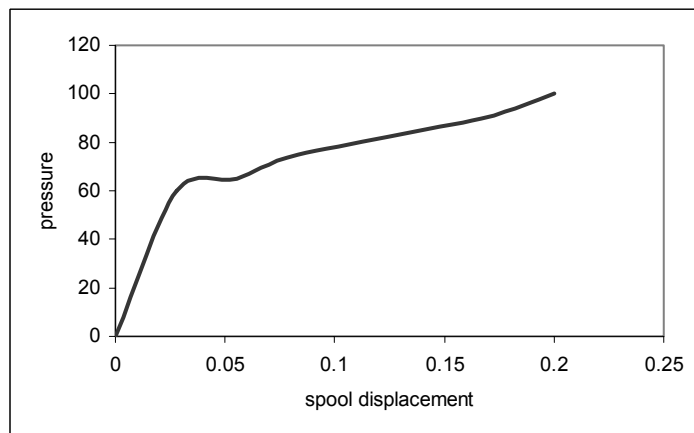


Fig. 10 Pressure gain Characteristics

## **5. Conclusion**

Non-linear flow requirements are essential in achieving twin objectives of fine laying and high slewing speeds for a flow control valve. These essential requirements for precise positioning of weapon platforms were met by appropriate selection of port configuration. The difficulties in manufacture and problems of leakage at null and jump at transition zones were over come by suitably shaping the spool land of the valve. The test results have shown fine control over complete operation range with smooth profile even at transition zones. The joysticks prepared with this valve configuration were successfully integrated in the armoured fighting vehicles and met the desired specifications.

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