Multi-Functional Loader Steering Hydraulic System model construction and simulation Based on Power Bond Graphs

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Abstract

Hydraulic steering system has been extensively applied in small type of loader and other engineering vehicles due to its special superiority, how to forecast its dynamic behavior in design stage is most important problem. This paper firstly analyse a typical steering hydraulic system of multi-functional loader, and construct its powder bond graphs, then decuce its state equations. With these equations, some hydraulic component have been encapsulated in soft Mworks, at last, a simpled steering hydraulic dynamic simulation model was constructed by these components, and some characteristic curves of system can be easily abtained.

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Keywords: Hydraulic steering system; Multi-functional Loaer; Power bond graphs; Dynamic simulation

Nomenclature

\begin{tabular}{|l|l|}
\hline
\textbf{Im} & Loading inertia \\
\textbf{Rf} & Loader resistance force \\
\textbf{Revl, Rev2, Rev3, Rev4} & The four hydraulic resistance of control valve \\
\textbf{C1, C2} & The two capacitis of control valve \\
\textbf{Pcvl \sim Pcv17} & The pressure in power bond graph of control valve \\
\textbf{Qcvl \sim Qcv17} & The flux in power bond graph of control valve \\
\textbf{Pcfl \sim Pcl17} & The pressure in power bond graph of cylinder \\
\textbf{Qcfl \sim Qcl17} & The flux in power bond graph of cylinder \\
\textbf{Vcvl \sim Vcv24} & The velocity of power bond graph of control valve \\
\textbf{Vcfl \sim Vcfl24} & The velocity of power bond graph of cylinder \\
\hline
\end{tabular}
The force of power bond graph of cylinder

The force of power bond graph of control valve Structure

Loading momentum

The pressure of tank

The pressure of pump

0. Introduction

Multi-functional loader is a kind of engineering mechanism in digging cubic metre of earth and stone, which was widely used in architecture, road, mining area and other fields [1]. The steering of loader is its important device and effect loader’s production coefficient and economical efficiency, so rational designing operator system has remarkable meaning. Power bond graph is used to setup dynamic mathematic model at the view of energy flow because the limitation of traditional method, this tool is effective method in hydraulic dynamic analysis, it can express the power flow process, including the power flow direction, allocation, energy transformation etc under kinds conditions of system[2][3][4]. It is necessary process to make these power flow process as graph before constructing simulation of system, there are two advantages, in one side, power bond graph can visualized describe corresponding relationship between modular structure and system every parts physic structure and dynamic factors; in other side, power bond graph keep strictly concordance with system state equations, so system mathematic model can be induced by power bond graph. This paper includes following steps: 1) analysing a typical steering hydraulic system of multi-functional loader; 2) constructing its powder bond graphs; 3) deducing its state equations. With these equations, some hydraulic component have been encapsulated in soft Mworks, 4) a simple steering hydraulic dynamic simulation model was constructed by these components, and some characteristic curves of system can be easily obtained.

1. Analysis of multi-functional loader’s hydraulic steering system

The research object in this paper is a type of hinged multi-functional loader, it consists two parts of carriages, and the two parts were joined by hinge pin shaft, which can keep or change carriage and back carriage walking as relative angle in different curved conduits. The steering system of this loader consists: steering device; controlling valve, and steering oil cylinder etc. The movement of execution element flows the track of controlling component. The working principle of multi-functional loader steering system is showing Fig 1.

\[
F_{c1} \sim F_{c23} \quad \text{The force of power bond graph of cylinder}
\]

\[
F_{cv1} \sim F_{cv23} \quad \text{The force of power bond graph of control valve Structure}
\]

\[
P_20 \quad \text{Loading momentum}
\]

\[
S_e \quad \text{The pressure of tank}
\]

\[
S_f \quad \text{The pressure of pump}
\]
with proportion by converter, there are some errors which gernerated by position signal $x_0$ and excution position signal, these errors breek the mid-position statement of spool in body of valve (steering controlling valve), these errors also changed original valve port size, and supply the pressure oil to steering oil cylinder, and the cylinder rod now is moving, the movement is output to carriage wheel and make a turing of loader. The steering hydraulic system is simplified as fig 2.

![Fig 2 Simplified hydraulic steering system of multi-functional loader](image)

The oil cylinder is working by pressure which offered by pump, the flux of pump is controlled by steering controlling valve, and redundant oil flow back to tank through overflow valve. The loading of whole steering system is simplified driving inertia $I_m$, friction resistance $R_f$, when power bond graph is constructing, the main factor need to be took consideration is steering controlling valve’s effects to whole system. The spool displacement $x_v$ is system input signal, it was converted from steering wheel, there are 4 hydraulic resistance orifices when there are relative displacement between spool and valve pocket. When the value of $x_v$ is zero, the value of 4 hydraulic resistance is infinite, when the value of $x_v$ is changing, the value of 4 hydraulic resistance is also changing with $x_v$.

2. Power bond graph and state equation derivation of steering hydraulic system

After analysing the principle of steering hydraulic system, the power bond graph is showing as Fig 3. The power bond graph don’t take consideration of resistance and volume of valve to cylinder, and make following assumption: the flux of pump is constant, and overflow valve isn’t working when deducing equation, the focal point is paying attention to the alteration of controlling valve $C_1, C_2$, because when the cylinder is moving, the alteration of $C_1, C_2$ will make important influent to whole system. There are 3 power storage components, so the state equations of system is 3 orders, the state variables are: two volumes of controlling valve $C_1, C_2$ and loading momentum $P_{20}$. 
4) According to rules of power bond graph and logic relationships of variables, here give the deducing process of state variables first order derivative:

\[ \dot{Q}_{cv16} = Q_{cv16} = Q_{cv15} - Q_{cv17} \]  

\[ Q_{cv15} = Q_{cv4} - Q_{cv5}, \quad Q_{cv4} = Q_{cv2} - \left( \frac{S_f}{P_{cv1}} \right), \quad Q_{cv5} = Q_{cv7} \]

\[ Q_{cv17} = A_1v_{cl18} = A_1v_{cl20} \]

So after substitute \( Q_{cv15}, Q_{cv17} \) to equation(4), we can obtain the \( \dot{v}_{cv16} \) first order derivative like eq (5):

\[ \dot{v}_{cv16} = \left( \frac{S_f}{P_{cv1}} \right) - Q_{cv7} - A_1 \cdot \frac{P_{20}}{I_m} \]  

\[ \dot{v}_{cv23} = Q_{cv23} = Q_{cv22} - Q_{cv24} \]

\[ Q_{cv22} = v_{cl21}, A_2 = v_{cl20}, A_2 = \frac{P_{20}}{I_m}, A_2, \quad Q_{cv24} = Q_{cv11} = Q_{cv9} \]

So after substitute \( Q_{cv22}, Q_{cv24} \) to equation(4), we can obtain the \( \dot{v}_{cv23} \) first order derivative like eq (7):

\[ \dot{v}_{cv23} = Q_{cv23} = Q_{cv22} - Q_{cv24} \]

\[ Q_{cv22} = v_{cl21}, A_2 = v_{cl20}, A_2 = \frac{P_{20}}{I_m}, A_2, \quad Q_{cv24} = Q_{cv11} = Q_{cv9} \]
\[ \dot{v}_{cv23} = \frac{P_{20}}{I_m} \cdot A_2 - Q_{cv9} \]  \hspace{1cm} (7)

\[ F_{20} = \dot{P}_{20} = F_{cl18} - F_{cl19} - F_{cl21} \]  \hspace{1cm} (8)

\[ F_{cl18} = \frac{P_{cl17}}{A_1} = \frac{P_{cl16}}{A_1} = \frac{v_{16}}{C_1 \cdot A_1} \]

\[ F_{cl19} = R_f \]

\[ F_{cl21} = \frac{P_{cl22}}{A_2} = \frac{v_{cl23}}{C_2 \cdot A_2} \]

So after substitute \( F_{cl18}, F_{cl19}, F_{cl21} \) to equation (8), we can obtain the \( P_{20} \) first order derivative like eq (9):

\[ F_{20} = \frac{v_{cl16}}{C_1 A_1} - R_f - \frac{v_{cl23}}{C_2 A_2} \]  \hspace{1cm} (9)

\[ Q_{cv7} + Q_{cv9} = Q_{cv8} = S_e, \text{ here suppose } Q_{cv7} = Q_{cv9}, \text{ so we can obtain the whole system state} \]

equation (1):

\[
\begin{align*}
V_{16} &= \left( \frac{S_f}{P_{cv1}} \right) - S_e - A_1 \cdot \frac{P_{20}}{I_m} \\
\dot{v}_{cv23} &= \frac{P_{20}}{I_m} \cdot A_2 - S_e \\
F_{20} &= \frac{v_{cl16}}{C_1 A_1} - R_f - \frac{v_{cl23}}{C_2 A_2}
\end{align*}
\]  \hspace{1cm} (10)

3. Hydraulic component packaging and simulation analysis

To construct simulation model easily, based on the modular analysis of power bond graph, some steering hydraulic components are packaged, and constructs a hydraulic library. Then builds completed steering system model. All works were finished by Mworks soft which developed by Tongyuan company. Fig 4 is showing the controlling valve packaged model, Fig 5 is showing the oil cylinder packaged model, Fig 6 is showing the overflow valve packaged model, and a completed simulation of steering hydraulic system model is showing with Fig 7.

a) The controlling valve power bond graph  

b) The packaged controlling valve model

Fig 4 controlling valve packaged model
After finishing steering hydraulic system model, there are virtual simulation test in steering working process. The simulation initial condition is listing in table 1, and some simulaiton results have been obtained. The initial condition is: the flux of pump: 1.0e-3 m³/s, the leakage coefficient: 5.0e-12 m³/s. the overflow valve: (valve closed if dp smaller): 190 bar, popen: (valve wide open if dp higher): 205 bar, conductance of leakage of closed valve, 1.111e-12 m³(s.Pa). The conductance of wide open overflow valve, 1.666e-9 m³(s.Pa). Steering controlling valve’s nominal flow rate: 8.333e-4 m³/s, pressure drop at qnom: 15 bar, diameter of equivalent orifice to model leakage of closed valve is 0, natural frequency of spool is 500 rad/s, damping coefficient of spool is 0.7, overlap relative to max displacement is 0.1, half of hysteresis width is 0.05, max spool velocity 100/s. Then, we can obtain following simulation curves like fig 9-fig14. Fig 8 a is showing controlling signal- squal wave curves, and Fig 9 is showing exit pressure curve of pump, Fig 10 is the flux of pump, Fig 11 is the displacement of steering oil cylinder, Fig 12 is the velocity of steering spool A part.
4. Conclusion

After analysing the steering hydraulic system, according to actual parameters of a multi-functional loader, this paper successfully constructs an interpreted simulation model, and simulates its typical working state. The results agree with the actual system circuit pressure and flux characteristics, the model can gain any points' pressure and flux condition. At the same time, through modifying model parameters and system components, we can easily know the influence of special elements.

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