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Research on Extension Element Model in Hydraulic System

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***Abstract* - After having analyzed hydraulic components and hydraulic systems, this paper presents a method of design hydraulic component and organizing hydraulic system with the matter-element in extension theory. As any hydraulic component contains three performance characteristics: input, output and nature, a hydraulic component can be described as a matter-element. Any hydraulic system is a system which inputs one kind of energy and outputs another kind of energy by interaction between hydraulic components. A hydraulic component is not only one particular type of hydraulic components, but also a part of a hydraulic system, thus this paper creates a matter-element and relation-element model of hydraulic systems, which is consisted of three parts: prototype of hydraulic component, description of hydraulic component with matter-element and relation-element, description of hydraulic system with matter-element and relation-element. Thus, a hydraulic system is organized to an extension element system that has outward input/output needs and contains components with internal function characteristic information. The extension element model in hydraulic system is obtained by integrating performance characteristics, external interface of hydraulic components, and the method of power bond graph. The study of extension element model in hydraulic system can presents a method of describing and storing hydraulic system and a dynamic model of hydraulic system, which has a vital significance for design and automation of hydraulic system.**

Index Terms - Power bond graphs, Hydraulic system, Matter-element, Extension, prototype

I. Introduction

Hydraulic systems are used to control the position or speed of resisting loads. They are power-transmitting assemblies employing pressurized liquid to transmit energy from an energy-generating source to an energy-use area [1]. A hydraulic system is consisted of hydraulic circuits which contain hydraulic element and have control function [2].

In 1983, professor Cai [3] proposed a concept of the extension set to solve the non-compatible problems and which proclaimed the birth of a theory: Extenics. The objective of extenics is to study the rules and methods of solving contradictory problems by employing the formalized tools, i.e., qualitative and quantitative analysis. With the matter-element as the basic logical cell, the matter-element theory and extension set theory are the pillars of the extenics. Extenics is an emerging science; recently it has been applied in various fields, say, economy, management, control, artificial intelligence, etc. [4][5][6]. Since the matter-element framework provides a formalized language to analyze matters in an overall way, it is preliminarily adopted to depict the functionality and features of hydraulics in this paper.

Any hydraulic component has itself performance characteristics. A matter-element model of hydraulic components is consisted of its performance characteristics and the value of these performance characteristics decided by the design and manufacture. An extension model of a hydraulic system is consisted of its performance characteristics and hydraulic components. A hydraulic system is a power transducing, power transmitting system [7][8]. Typically, power is drawn from a source such as an electric mains supply, diesel engine, aircraft engine, etc., and progressively converted and transmitted to a mechanical form useable at the driven load. Power flow modeling, and in particular its extension power bond graphs, provides the designer of powered control systems with a dynamic modeling procedure which is more fundamental to, and more useable in the system design environment [1]. This paper gives a method integrating performance characteristics, external interface of hydraulic components, and the study method of power bond graph.

The study on hydraulic system with the method of extension theory can create many new technology and method to design, produce and organize hydraulic system. For the convenience of discussion, this paper has first studied the nature of hydraulic systems and characteristics and performances of their components, then constructs their matter-element model. Finally, it presents a description and organization method of hydraulic systems on matter-element theory through computing between matter-elements.

II. Implementation Points of Extension Model in Hydraulic System

Based on characteristics of hydraulic system, this paper puts forward a program of extension organization in hydraulic system which is expected to cover the following aspects:

1) Design and organization of hydraulic component prototype. Although hydraulic components occupy different features because of the particular needs of design and manufacture, hydraulic components have the same or similar functions in hydraulic systems. Therefore they can be designed and organized with hydraulic component prototype.

2) The matter-element and relation-element model of hydraulic components. The matter-element and relation-element model of hydraulic components designed by this

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paper can contain more concrete characteristics of hydraulic components and conveniently use in hydraulic system design.

3) Organization and description of hydraulic system. The organization and description model of hydraulic systems can descript the exchange of information or energy between a hydraulic system and its outside, and contain all hydraulic components in this hydraulic system.

III. THE ANALYSIS OF HYDRAULIC COMPONENTS

Hydraulic systems are composed of energy device, actuator, control component, ancillary equipment and work media. Hydraulic components mainly refer to energy device, actuator, control component, ancillary equipment. The work media flows between hydraulic components, transmits the information of system control and movement [8].

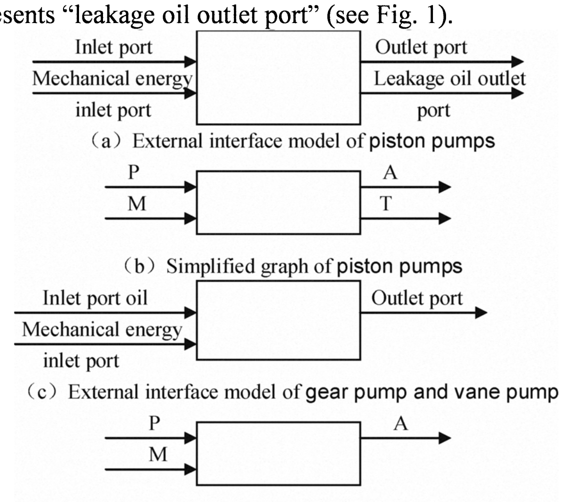
Any hydraulic component has itself performance characteristics decided by the design principle, the manufacture method and the material. Hydraulic components with the same or similar function often have the same or similar performance characteristics [8].

A. The hydraulic components of energy device

This paper takes hydraulic pumps as an example to illustrate the characteristics of components of energy device. All pumps should have the main performance characteristics, such as suction pressure, working pressure, rated pressure, adjusting pressure range, output pressure, pressure classification, displacement, max adjusting displacement, max displacement, geometric displacement, theoretical displacement, output flow, driving power, speed range, driving torque, power consumption, rotation speed, mechanical efficiency, volumetric efficiency, total efficiency, input power, output power and so on. Because there are some intrinsic relations between these performance characteristics, some characteristics can be obtained by computing other characteristics. Therefore the performance characteristics of concrete pump are different. The performance characteristics of gear pump are displacement, rated pressure, output flow, driving power, speed range and so on. The performance characteristics of vane pump are geometric displacement, pressure classification, direction of rotation and so on. That is say that the main performance characteristics of pumps contain pressure and its range, displacement and its range, rotation speed and its range, torque and its range, volumetric efficiency, total efficiency and so on [8][9][10].

From the perspective of power bond graphs pumps convert mechanical energy to hydraulic energy, therefore pumps input mechanical energy, output hydraulic energy, and have leakage, windage or friction force loss in the work process [1]. Mechanical energy is usually associated with the rotation speed and torque; hydraulic energy is usually associated with the pressure and displacement.

External interfaces are also key Characteristics of pumps. The hydraulic oil enters a pump from its inlet port, flows out from its outlet port [2][7]. The mechanical energy enters a pump with its axis which connects an electric motor. For the convenience of discussion, this paper view this working way as the "mechanical energy inlet port". The leakage oil is seen as the outflow from the "leakage oil outlet port". The letter P represents inlet port, the letter A represents outlet port, the letter M represents "mechanical energy inlet port", the letter T represents "leakage oil outlet port" (see Fig. 1).



(a) External interface model of piston pumps

(b) Simplified graph of piston pumps

(c) External interface model of gear pump and vane pump

(d) Simplified graph of gear pump and vane pump

Fig.1 External interface model and Simplified graph of energy device

Obviously, the performance characteristics of pump can contain three aspects:

1) Input characteristics: The performance characteristics describing the input of pumps are called input characteristics;

2) Output characteristics: The performance characteristics describing the output of pumps are called output characteristics;

3) Nature characteristics: The performance characteristics decided by the design and the manufacture are nature characteristics. Volumetric efficiency, total efficiency and transfer function of pumps are nature characteristics. Nature characteristics are intrinsic, fixed and inevitable.

B. The hydraulic components of actuator

This paper takes hydraulic motors and cylinders as an example to illustrate the characteristics of components of actuator. The performance characteristics of hydraulic motor are displacement, pressure, speed range, rated output and so on. The performance characteristics of cylinder are normal pressure, bore size, rod diameter, max stroke, pressure, flow and so on [8][9][10]. Some performance characteristics are decided by the design and the manufacture. The mechanical energy outputs from a motor with its axis which connects the load, outputs from a cylinder with its rod which connects the load , this paper view this working way as the "mechanical energy outlet port" and represented by the letter M. Motors have an inlet port and an outlet port, the fluid port of cylinders is not only an inlet port, but also an outlet port. The letter P represents inlet port, the letter A represents outlet port, so A|P represents an inlet port that is same an outlet port. Double-acting cylinders have two fluid ports, one is represented by the letter A, and another is represented by the letter B. Obviously, the performance characteristics of actuator can contain three aspects: input characteristics, output characteristics, nature characteristics (see Fig. 2).

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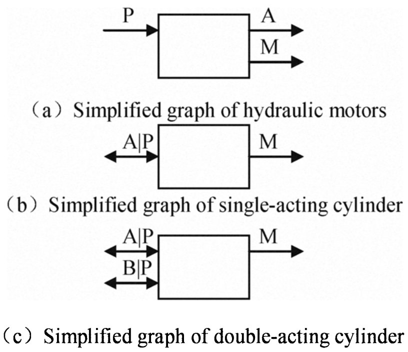


（c）Simplified graph of double-acting cylinder

Fig. 2 Simplified graph of actuator

C. The hydraulic components of control component

Control components in hydraulic system are hydraulic valves. Hydraulic valves are various. The performance characteristics of hydraulic valves have displacement, pressure and so on. Some hydraulic valves have the hand lever which controls the work pattern of hydraulic valves. This position work as a hand lever can be electron and hydraulic [8][9][10]. These which can control the work model of hydraulic valves are abstracted as an "electron/mechanical /hydraulic control port", represented by the letter C. Pressure ports are represented by the letter P, outlet ports and A outlet ports are represented by the letter A, B outlet ports are represented by the letter B, tank ports are represented by the letter T. Obviously, the performance characteristics of control component can contain three aspects: input characteristics, output characteristics, nature characteristics. The performance characteristics of "electron/mechanical/hydraulic control port" belong to input characteristics. Some valves have an "electron/mechanical/hydraulic control port" of A outlet port and an "electron/mechanical/hydraulic control port" of B outlet port, the former is called by "A electron/mechanical /hydraulic control port", represented by A|C, the latter is called by "B electron/mechanical/hydraulic control port", represented by B|C. In Fig.3 hydraulic valves are divided into five categories as following:

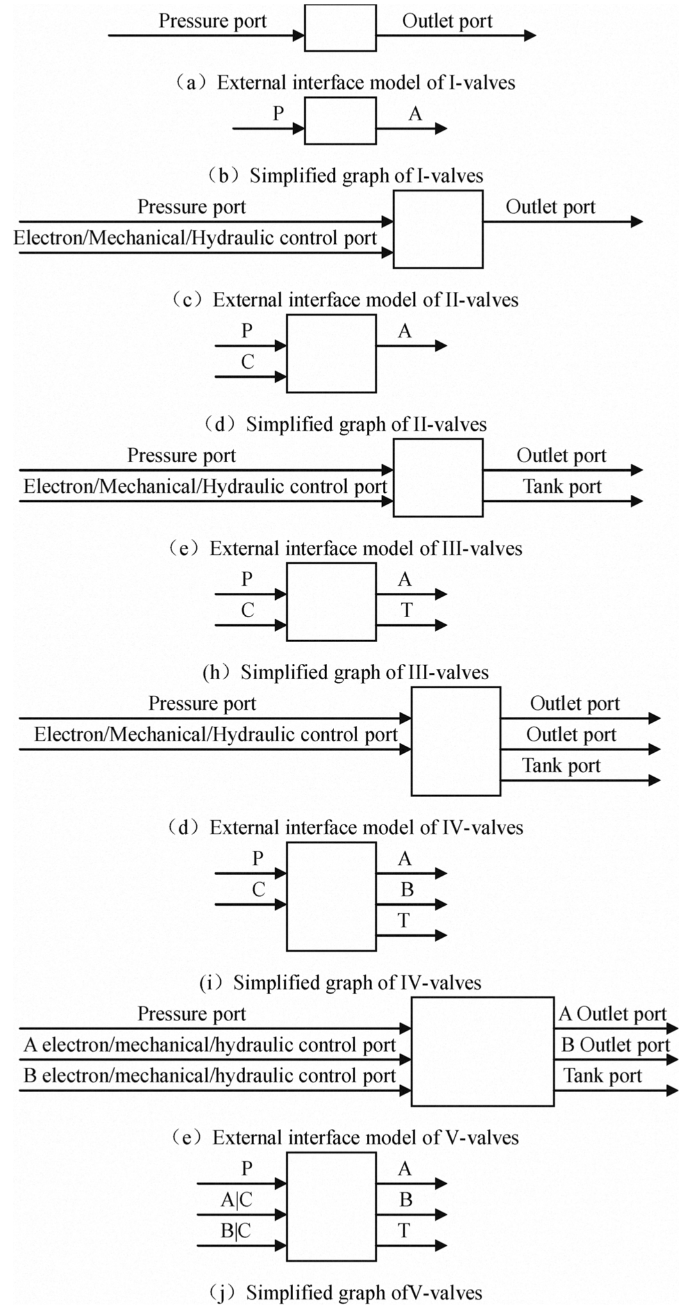
1) The valves which only have an inlet port and an outlet port, are called I-valves, for example, check valves are I-valves;

2) The valves which have an inlet port, an outlet port and an "electron/mechanical/hydraulic control port", are called II-valves, for example, restrictive valves are II-valves;

3) The valves which have an inlet port, an outlet port, an tank port and an "electron/mechanical/hydraulic control port", are called III-valves, for example, pressure relief valves are III-valves;

4) The valves which have an inlet port, two outlet ports, an tank port and an "electron/mechanical/hydraulic control port", are called IV-valves, for example, reversing valves are IV-valves;

5) The valves which have an inlet port, two outlet ports, an tank port and two "electron/mechanical/hydraulic control ports", are called V-valves, for example, proportional valves are V-valves. For V-valves, the change of signal of "electron /mechanical/hydraulic control ports" can make the change of hydraulic signal of the outlet port corresponding to this port.



（j）Simplified graph ofV-valves

Fig. 3 External interface model and Simplified graph of control components

D. The hydraulic components of ancillary equipment

Ancillary equipments are easy. Pipes may be understood to a hydraulic component that has an inlet port and an outlet port, accumulators, filters, reservoirs, heat exchangers, pressure gauges, pressure intensifiers are the same, also [8][9][10]. All of ancillary equipments can be represented by fig. 4. The inlet ports are represented by the letter P, the outlet ports are represented by the letter A. Obviously, the performance characteristics of ancillary equipment can contain three aspects: input characteristics, output characteristics, nature characteristics, also (see Fig. 4).

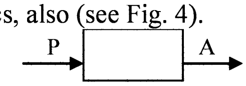


Fig. 4 Simplified graph of ancillary equipments

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IV. THE MEANING OF MATTER-ELEMENT AND RELATION-ELEMENT IN EXTENICS

A matter-element, which is denoted by an ordered triad R= (N,c,v), is a basic element abstracting a matter, where N represents the matter, c is a characteristic of N, v= c(N) is the measure about the characteristic c, and (c,v) is a feature-element of matter N. A matter may have many feature-elements, and it can be expressed by an n-dimensional matter-element as:

$$R=(N,C,V)=\begin{bmatrix} N & c_1 & v_1 \\ & c_2 & v_2 \\ & c_3 & v_3 \\ & \cdots & \cdots \\ & c_n & v_n \end{bmatrix}=\begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ \cdots \\ R_n \end{bmatrix}$$

$R_i=(N,c_i,v_i)$，(i=1,2,...，n) is called the branch matter of R [3][4][5].

The definition of relation-element can give in a similar way. Regardless of being the matter-element or relational element, their measure may be number and non-number [3][4][5].

V. THE CONSTRUCTION OF HYDRAULIC COMPONENT PROTOTYPE

The prototype of hydraulic component is abbreviated by PHC.

Performance characteristics of hydraulic component can be classed three categories, they are input characteristics, output characteristics and nature characteristics. Not only input characteristics, but also output characteristics and nature characteristics are various. The set collecting these performance characteristics can descript characteristics of a hydraulic component.

Definition 1: A matter-element which has a characteristic and a measure about this characteristic is called a matter-element unit, abbreviated by MEU. The matter name is named by a set.

Obviously, matter-element units can descript one of performance characteristics of hydraulic components. TABLE I gives some matter-element units in hydraulic system.

Definition 2: The characteristic and the measure of a matter-element unit is empty, this matter-element unit is called an empty unit, abbreviated by EU.

Obviously, empty units are special matter-element units. TABLE II gives some empty units in hydraulic system.

Definition 3: $\forall [N_i \ \ c_i \ \ v_i], [N_j \ \ c_j \ \ v_j]$, i, j=1,2,…,n, are matter-element units. $[N_i \ \ c_i \ \ v_i] \oplus [N_j \ \ c_j \ \ v_j] = [N_i \oplus N_j \ \ c_i \oplus c_j \ \ v_i \oplus v_j]$, if $N_i \oplus N_j = N_i \cup N_j$，$c_i \oplus c_j = c_i \vee c_j$，$v_i \oplus v_j =$ v_i□v_j. The operation □ is called merge operation.

Obviously, $\oplus$ has nature characteristics as following:

1) The result of a matter-element unit merged itself is still itself;

2) $\oplus$ satisfies commutative law;

3) The merge result of any two empty units is still an empty unit. For example, $[\{A\} \ \ \Phi \ \ \Phi] \oplus [\{P\} \ \ \Phi \ \ \Phi]$ can be expressed by A|P, A|P is an empty unit. $[\{A\} \ \ \Phi \ \ \Phi] \oplus [\{P\} \ \ \Phi \ \ \Phi] = [\{A,P\} \ \ \Phi \ \ \Phi]$. So, A|C, B|C are empty units also. A|P, A|C, B|C can descript external interfaces of hydraulic components, and A|P and P|A is same.

TABLE I
THE MAIN MATTER-ELEMENT UNITS

The name of a matter-element unit	Definitions
Voltage matter-element	$[\{vol\} \ \ vval \ \ [x,y], \forall x,y \ge 0 andx \langle y]$
Current matter-element	$[\{cur\} \ \ cval \ \ [x,y], \forall x,y \ge 0 andx \langle y]$
Torque matter-element	$[\{tor\} \ \ tval \ \ [x,y], \forall x,y \ge 0 andx \langle y]$
Rotational speed matter-element	$[\{rots\} \ \ sval \ \ [x,y], \forall x,y \ge 0 andx \langle y]$
Pressure matter-element	$[\{pre\} \ \ pval \ \ [x,y], \forall x,y \ge 0 andx \langle y]$
Stroke matter-element	$[\{str\} \ \ stva \ \ [x,y], \forall x,y \ge 0 andx \langle y]$
Displacement matter-element	$[\{dis\} \ \ diva \ \ [x,y], \forall x,y \ge 0 andx \langle y]$
Switch matter-element	$[\{sw\} \ \ swv \ \ \{x\}, x \in \{0,1\}, switchon, x=1; others, x=0]$
Transfer function matter-element	$[\{tra\} \ \ tval \ \ \{transfer-function-formula\}]$
Total efficiency matter-element	$[\{toe\} \ \ teva \ \ \{x\%\}, x \ge 0]$
Volumetric efficiency matter-element	$[\{voe\} \ \ veva \ \ \{x\%\}, x \ge 0]$
Rotation direction matter-element	$[\{rod\} \ \ rval \ \ \{x\}, x \in \{0,1\}, clockwise, x=1; \text{others}, x=0]$
Output direction matter-element	$[\{oud\} \ \ odva \ \ \{x\}, x \in \{0,1\}, \text{A-outlet}, x=1; \text{B-outlet}, x=0]$
Input direction matter-element	$[\{ind\} \ \ idva \ \ \{x\}, x \in \{0,1\}, A-inlet, x=1; \text{B-inlet}, x=0]$
Input variable matter-element	$[\{inv\} \ \ ivva \ \ \{x\}, \ x \in R]$
Output variable matter-element	$[\{ouv\} \ \ ovva \ \ \{x\}, \ x \in R]$

TABLE II
THE MAIN EMPTY UNITS

The name of empty units	Definitions	Significance
A unit	$[\{A\} \ \ \Phi \ \ \Phi]$	A
B unit	$[\{B\} \ \ \Phi \ \ \Phi]$	B
P unit	$[\{P\} \ \ \Phi \ \ \Phi]$	P
T unit	$[\{T\} \ \ \Phi \ \ \Phi]$	T
M unit	$[\{M\} \ \ \Phi \ \ \Phi]$	mechanical
E unit	$[\{E\} \ \ \Phi \ \ \Phi]$	electron
H unit	$[\{H\} \ \ \Phi \ \ \Phi]$	hydraulic
C unit	$[\{C\} \ \ \Phi \ \ \Phi]$	control

4) The merge result of a matter-element unit in TABLE I and a empty unit in TABLE II is a matter-element unit. This merge can descript performance characteristics of hydraulic component. For example, $[\{dis\} \ \ diva \ \ [x,y], \forall x,y \ge 0 andx \langle y]$ $\oplus$ $[\{A\} \ \ \Phi \ \ \Phi]$ = $[\{dis, A\} \ \ diva \ \ [x,y], \forall x,y \ge 0 andx \langle y]$ can descript the displacement value range of A outlet port of hydraulic components. The empty unit as A|P, A|C, B|C can be merged with the matter-element unit in TABLE I also.

5) The merge result of two matter-elements in TABLE I isn't a matter-element. It is a merge matter-element. Because characteristics of two matter-elements in TABLE I are incompatible, they can not merge together. $\forall [N_i \ \ c_i \ \ v_i]$, $[N_j \ \ c_j \ \ v_j]$, i,j=1,2,…,n, are matter-element units in TABLE I, $[N_i \ \ c_i \ \ v_i] \oplus [N_j \ \ c_j \ \ v_j] = \begin{bmatrix} N_i \cup N_j & c_i & v_i \\ & c_j & v_j \end{bmatrix}$.

6) The merge result of an empty unit and the merge result of two matter-element units in TABLE I , and the merge result of the merge result of two matter-element units in TABLE I and an empty unit, is same.

If input characteristics of hydraulic component are abbreviated by ICHC, and output characteristics of hydraulic component are abbreviated by OCHC, and nature characteristics of hydraulic component are abbreviated by NCHC, prototype of hydraulic component are abbreviated by PHC,

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then the prototype of a hydraulic component can be described by a PHC as following:

$$\begin{bmatrix} \text{The name of prototype} & \text{ICHC} & \text{set of MEU} \\ & \text{OCHC} & \text{set of MEU} \\ & \text{NCHC} & \text{set of MEU} \end{bmatrix} \quad (1)$$

VI. THE CONSTRUCTION OF MATTER-ELEMENT AND RELATION-ELEMENT MODEL OF HYDRAULIC COMPONENTS

The matter-element and relation-element model of hydraulic components is abbreviated by MRMHC.

A hydraulic component can input from other components, and output to other components, has a PHC itself. If the set of inputs from other components is abbreviated by SIOC, and the set of outputs to other components is abbreviated by SOOC, and the PHC of a hydraulic component is abbreviated by PHCC, a hydraulic component can be described by a MRMHC as following:

$$\begin{bmatrix} \text{The name of component} & \text{inputs} & \text{SIOC} \\ & \text{outputs} & \text{SOOC} \\ & \text{PHC} & \text{PHCC} \end{bmatrix} \quad (2)$$

VII. THE CONSTRUCTION OF MATTER-ELEMENT AND RELATION-ELEMENT MODEL OF HYDRAULIC SYSTEM

The matter-element and relation-element model of hydraulic systems is abbreviated by MRMHS.

A hydraulic system can input from its outside, and output to its outside, has many components. If the set of inputs from outside is abbreviated by SFO, and the set of outputs to outside is abbreviated by STO, and the set of components in a hydraulic system is abbreviated by SOC, and the set of components is abbreviated by SC, a hydraulic system can be described by a MRMHS as following:

$$\begin{bmatrix} \text{The name of hydraulic system} & \text{inputs} & \text{SFO} \\ & \text{outputs} & \text{STO} \\ & \text{SC} & \text{SOC} \end{bmatrix} \quad (3)$$

VIII. THE EXTENSION ELEMENT MODEL OF HYDRAULIC SYSTEMS

Inputs and outputs of MRMHC and MRMHS are complex. For the convenience of discussion, this paper gives rules as following:

1) When a man is an operator of a hydraulic system, he or she will be seen an element of the hydraulic system. But he or she exists independently and is free of a hydraulic system, therefore it is not necessary to define him or her in this hydraulic system.

2) Give a merge operator between a MRMHC and an empty unit:

Definition 4: $\forall [X \quad \Phi \quad \Phi], [X \quad \Phi \quad \Phi]$ is an empty unit, Y is a MRMHC, $[X \quad \Phi \quad \Phi] \oplus Y$ is true if $X \in \{y | y \in \bigcup_{k \subset K} k$,K is the matter name set of matter-elements of PHC-component in Y$\}$. $\oplus$ is called merge operation between a MRMHC and an empty unit.

Therefore, an empty unit and a MRMHC can merge and descript the information of external interfaces of hydraulic components.

Give an example for extension element model of hydraulic system as following. Fig.5 gives a hydraulic circuit.

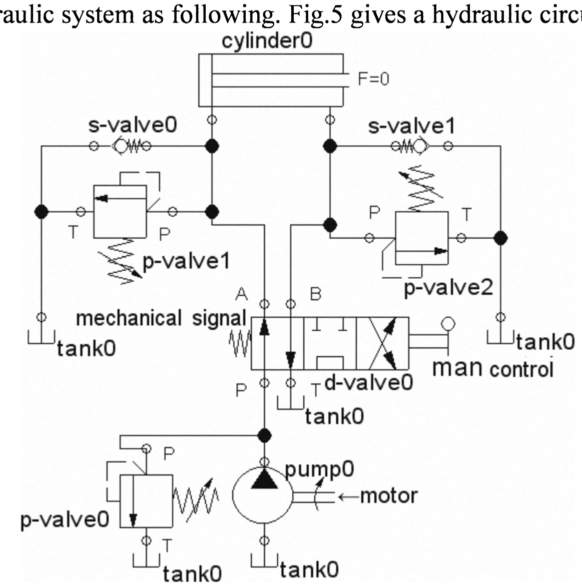

Fig. 5 A hydraulic circuit

The MRMHS of Fig. 5 is

$$\begin{bmatrix} \text{h - system} & \text{inputs} & \{\text{motor} \oplus \text{M}\} \\ & \text{outputs} & \{\text{cylinder0} \oplus \text{M}\} \\ & \text{SC} & \{\text{pump0, d - valve0, cylinder0,} \\ & & \text{p - valve0, p - valve1, p - valve2,} \\ & & \text{s - valve0, s - valve1, tank0}\} \end{bmatrix}$$

MRMHCs in Fig. 5 are listed as following

$$\begin{bmatrix} \text{cylinder0} & \text{inputs} & \{\text{d - valve0} \oplus \text{A, d - valver0} \oplus \text{B}\} \\ & \text{outputs} & \{\text{d - valve0} \oplus \text{A, d - valve0} \oplus \text{B,} \\ & & \text{cylinder0} \oplus \text{M}\} \\ & \text{PHC} & \text{cylinder} \end{bmatrix}$$

$$\begin{bmatrix} \text{pump0} & \text{inputs} & \{\text{tank0} \oplus \text{P, motor} \oplus \text{M}\} \\ & \text{outputs} & \{\text{d - valve0} \oplus \text{P, p - valve0} \oplus \text{P}\} \\ & \text{PHC} & \text{pump} \end{bmatrix}$$

$$\begin{bmatrix} \text{d - valve0} & \text{inputs} & \{\text{pump0} \oplus \text{A, cylinder0} \oplus \text{A,} \\ & & \text{cylinder0} \oplus \text{B, people} \oplus \text{C} \oplus \text{M} \\ & & \text{people} \oplus \text{M}\} \\ & \text{outputs} & \{\text{cylinder0} \oplus \text{A, s - valve0} \oplus \text{P,} \\ & & \text{p - valve1} \oplus \text{P, cylinder0} \oplus \text{B,} \\ & & \text{s - valve1} \oplus \text{P, p - valve2} \oplus \text{P,} \\ & & \text{tank0} \oplus \text{A}\} \\ & \text{PHC} & \text{d - valve} \end{bmatrix}$$

$$\begin{bmatrix} \text{p - valve0} & \text{inputs} & \{\text{pump0} \oplus \text{A, people} \oplus \text{M}\} \\ & \text{outputs} & \{\text{tank0} \oplus \text{A}\} \\ & \text{PHC} & \text{p - valve} \end{bmatrix}$$

$$\begin{bmatrix} \text{p - valve1} & \text{inputs} & \{\text{d - valve0} \oplus \text{A, people} \oplus \text{M}\} \\ & \text{outputs} & \{\text{tank0} \oplus \text{A}\} \\ & \text{PHC} & \text{p - valve} \end{bmatrix}$$

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$$\begin{bmatrix} \text{p - valve2} & \text{inputs} & \{\text{d - valve0} \oplus \text{B}, \text{people} \oplus \text{M}\} \\ & \text{outputs} & \{\text{tank0} \oplus \text{A}\} \\ & \text{PHC} & \text{p - valve} \end{bmatrix}$$

$$\begin{bmatrix} \text{s - valve0} & \text{inputs} & \{\text{d - valve0} \oplus \text{A}\} \\ & \text{outputs} & \{\text{tank0} \oplus \text{A}\} \\ & \text{PHC} & \text{s - valve} \end{bmatrix}$$

$$\begin{bmatrix} \text{s - valve1} & \text{inputs} & \{\text{d - valve0} \oplus \text{B}\} \\ & \text{outputs} & \{\text{tank0} \oplus \text{A}\} \\ & \text{PHC} & \text{s - valve} \end{bmatrix}$$

PHCs needed in Fig. 5 as following:

$$\begin{bmatrix} \text{pump} & \text{ICHC} & \{\text{Displacement matter - element} \oplus \text{P}, \\ & & \text{Pressure matter - element} \oplus \text{P}, \\ & & \text{Torque matter - element} \oplus \text{M}, \\ & & \text{Rotational Speed matter - element} \oplus \text{M}\} \\ & \text{OCHC} & \{\text{Displacement matter - element} \oplus \text{A}, \\ & & \text{Pressure matter - element} \oplus \text{A}\} \\ & \text{NCHC} & \{\text{Transfer function matter - element}, \\ & & \text{Total efficiency matter - element}, \\ & & \text{volumetric efficiency matter - element}\} \end{bmatrix}$$

$$\begin{bmatrix} \text{cylinder} & \text{ICHC} & \{\text{Displacement matter - element} \oplus \text{P} \oplus \text{A}, \\ & & \text{Pressure matter - element} \oplus \text{P} \oplus \text{A}, \\ & & \text{Displacement matter - element} \oplus \text{P} \oplus \text{B}, \\ & & \text{Pressure matter - element} \oplus \text{P} \oplus \text{B}\} \\ & \text{OCHC} & \{\text{Displacement matter - element} \oplus \text{A}, \\ & & \text{Pressure matter - element} \oplus \text{A}, \\ & & \text{Displacement matter - element} \oplus \text{B}, \\ & & \text{Pressure matter - element} \oplus \text{B}, \\ & & \text{Pressure matter - element} \oplus \text{M}, \\ & & \text{Stroke matter - element}\} \\ & \text{NCHC} & \{\text{Transfer function matter - element}\} \end{bmatrix}$$

$$\begin{bmatrix} \text{d - valve} & \text{ICHC} & \{\text{Displacement matter - element} \oplus \text{P}, \\ & & \text{Pressure matter - element} \oplus \text{P}, \\ & & \text{Displacement matter - element} \oplus \text{P} \oplus \text{A}, \\ & & \text{Pressure matter - element} \oplus \text{P} \oplus \text{A}, \\ & & \text{Displacement matter - element} \oplus \text{P} \oplus \text{B}, \\ & & \text{Pressure matter - element} \oplus \text{P} \oplus \text{B}, \\ & & \text{Input direction matter - element} \oplus \text{C} \oplus \text{M}, \\ & & \text{Output direction matter - element} \oplus \text{C} \oplus \text{M}, \\ & & \text{Pressure matter - element} \oplus \text{M}\} \\ & \text{OCHC} & \{\text{Displacement matter - element} \oplus \text{T}, \\ & & \text{Pressure matter - element} \oplus \text{T}, \\ & & \text{Displacement matter - element} \oplus \text{A}, \\ & & \text{Pressure matter - element} \oplus \text{A}, \\ & & \text{Displacement matter - element} \oplus \text{B}, \\ & & \text{Pressure matter - element} \oplus \text{B}\} \\ & \text{NCHC} & \{\text{Transfer function matter - element}\} \end{bmatrix}$$

$$\begin{bmatrix} \text{s - valve} & \text{ICHC} & \{\text{Displaceme nt matter - element} \oplus \text{P}, \\ & & \text{Pressure matter - element} \oplus \text{P}\} \\ & \text{OCHC} & \{\text{Displaceme nt matter - element} \oplus \text{A}, \\ & & \text{Pressure matter - element} \oplus \text{A}\} \\ & \text{NCHC} & \{\text{Transfer function matter - element}\} \end{bmatrix}$$

$$\begin{bmatrix} \text{p - valve} & \text{ICHC} & \{\text{Displacement matter - element} \oplus \text{P}, \\ & & \text{Pressure matter - element} \oplus \text{P}, \\ & & \text{Pressure matter - element} \oplus \text{M}\} \\ & \text{OCHC} & \{\text{Displacement matter - element} \oplus \text{A}, \\ & & \text{Pressure matter - element} \oplus \text{A}\} \\ & \text{NCHC} & \{\text{Transfer function matter - element}\} \end{bmatrix}$$

In the condition that the former example neglects the effects of pipes, we can draw the following conclusions. Obviously, the hydraulic system organized by extension element model can not only contain the important information in hydraulic system, but also can provide the information needed by power bond graphs. The inner elements of components and the corresponding input and output which components need have to co-exist and usually interact with each other. A pair of connected hydraulic components, the output characteristic of the front and the input characteristic of the following contain the same information of MEU. This information of MEU directly decides whether interrelated hydraulic components can co-work and how they co-work, and the means with which they work harmoniously.

VIII. CONCLUSION

Although hydraulic components and hydraulic system are complex, the way provided by this paper still can solve the problem of description and organization of hydraulic system. The study on extension element model in hydraulic system can stimulate many new ideas and methods of researching hydraulic system, which has a vital significance for the design and automation of hydraulic system.

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