DECISION ANALYSIS OF DESIGNING GUIDELINES IN CONDITIONS OF UNCERTAINTY IN THE ANALYSIS OF DYNAMIC PROPERTIES OF MACHINE SYSTEMS

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Summary: The main problem of dynamics is to specify the stability of the system layout and then, the real system. The analysis of the stability can be considered from the point of view of stability of an element or the stability of the whole system. During the process of changing the values of construction and/or exploitation parameters it is possible that the whole system shows instability whilst singular elements of exploitation parameters are stable. This work presents an example of using the Quine - McCluskey algorithm together with common minimization of certain and uncertain canonical products while solving the complex decision process.

Keywords: logic functions system, Quine - McCluskey algorithm, optimization, overflow valve, multi-value logic functions.

1. Introduction

In the contemporary technology there are systems composed of sets of various physical character e.g. electric and mechanical, pneumatic, hydraulic, etc. Designing and analysing of such systems requires application of appropriate forms of description and research methods in order to apply an appropriate optimization procedure. Overflow machines form a large group of systems [1, 2, 3]. The work of overflow machines is most often based on two states: the transient state (the values of the system functions change in time) and the set state (the function values do not undergo changes in time or these changes occur from time to time). Changes of construction parameters x_1, x_2 ,…, x_n have an influence on the behaviour of the functions f_1, f_2 ,…, f_r depending on time *t.* In the optimization process, for the same changes of construction and/or exploitation parameters it is possible to observe different behaviour of functions depending on time [4].

Decision tables [5], logic functions [4, 6, 7, 8, 9, 10, 11] and graphs [12] can be applied in issues concerning modelling machine systems which are described by means of (ordinary or partial). differential equations. It results from the fact that occurring not linear elements can be divided into the finished number of linear elements (parts) what leads to receiving several linear systems in the meaning of modelling course from the prime single not linear system. A discrete optimization of overflow machine systems based on logic decision trees is aimed at defining the importance of construction and exploitation parameters that is guidelines concerning the sequence of decisions taken from the point of view of the realization of the system aim and stability function [6, 10, 11].

During the changing process of construction and/or exploitation parameters values it is possible that the whole system will show instability whilst single parameters will remain stable. The optimization procedure should include analytic or graphic dependencies linking exploitation parameters (pressure and flow intensity) with construction parameters e.g. the spring constant. If it is certain that the criteria condition is to be fulfilled only by some functions f_i from the set of functions f_r of a given set, than the optimization takes place in the conditions of uncertainty. This work presents an example of applying the Quine – McCluskey algorithm together with the common minimization of certain and uncertain canonical products while solving the complex decision process.

2. Quine - McCluskey algorithm of the minimization of multi-value logic functions

The Quine - McCluskey algorithm makes it possible to find all prime implicants of a given logic function that is there is a shortened alternative, normal form SAPN [11, 13]. The terms of incomplete gluing and elementary absorption have the main role in the search of prime implicants and are used for the APN of a given logic function.
The following transformation i s called the consensus operation:

$$Aj_o(x_r)+\ldots+Aj_{m_r-1}(x_r)=A \tag{1}$$

where: $r=1,\ldots,n$ and A - a partial elementary product, the literals of which possess variables belonging to the set: $\{x_1,\ldots,x_{r-i},x_{r+i},\ldots,x_n\}$.
The following transformation is called the operation of reduction:

$$Aj_u(x_r)+A=A \tag{2}$$

where $0\le u\le m_r-1$, $1\le r\le n$, and A - a partial elementary product, the literals of which possess variables belonging to the set: $\{x_1,\ldots,x_{r-1},\ \ x_{r+1},\ldots,x_n\}$.(If the above equation takes place, then A absorbs $Aj_u(x_r)$).

Example
Successive stages of the multi-value logic function minimization: *020, 101, 200, 021, 111, 201, 210, 022, 121, 202, 211, 212, 221* can be presented in the following way:

0	2	0
1	0	1
2	0	0
0	2	1
1	1	1
2	0	1
2	1	0
0	2	2
1	2	1
2	0	2
2	1	1
2	1	2
2	2	1

0	2	-
2	0	-
1	-	1
2	1	-
-	2	1
2	-	1

	020	200	101	021	201	210	111	022	121	202	211	212	221
02-	*			*				*					
20-		*			*					*			
1-1			*				*		*				
21-						*					*	*	
-21				*					*				*
2-1					*						*		*

In the end, two NAPN and MAPN of a given logic function are received and written in the form of the m-position numerical system: {(02-), (20-), (1-1), (21-), (-21)} and {(02-), (20-), (1-1), (21-), (2-1)}.

3. Decision analysis of designing guidelines in the analysis of dynamic parameters of the overflow valve

3.1. Overflow valve work

The overflow valve is used in the system in order to let the excess of the pressed liquid go to the reservoir when it turns out that the output of the pump exceeds the need. The Figure 1 presents the drive system of the engine with the overflow valve [14].

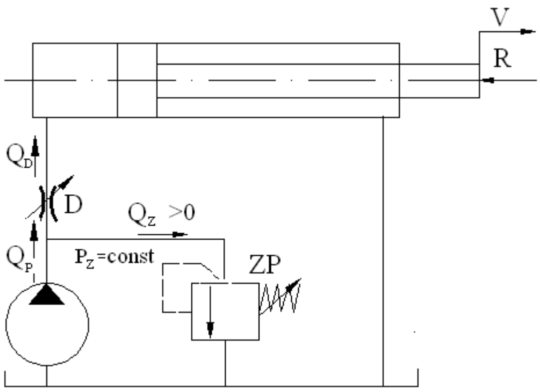

Fig. 1. The driving system of the engine with the overflow valve

In the set presented in the Figure 1, the speed of the piston movement is steered by means of the throttle D. As a result of which, only a part of the liquid stream pumped by the pump P comes to the actuator. The rest of the liquid stream ($Q_Z = Q_P - Q_D$) flows through the overflow valve ZP which must be constantly open because $Q_Z > 0$.

During the work of the overflow valve, it is necessary to take into consideration among others:

- static forces coming from the work force pressure),
- hydrodynamic forces,
- viscous friction forces,
- spring forces,
- forces resulting from the inertia of the liquid column.

Structural models are built in order to modify dynamic properties of flow systems and they reflect transformation properties of the system. Equations describing the flow of liquid through the valve (based on the mass conservation principle) are used in the construction of the valve model. There are two types of equations describing the valve work:

– the equation of forces acting on the valve seat,
– the equation of flows.

The equation of forces having an influence on the valve seat is presented in the following form:

$$\frac{Q_p^{\ 2}}{A_1}\rho+\rho\cdot A_2+\rho\cdot l\frac{dQ_p}{dt}=G_{ap}+S+k\cdot x+f\frac{dx}{dt}+m\frac{d^2x}{dt^2}+\Phi\sqrt{2\cdot\rho}\cdot\cos(v)\cdot Q_p\sqrt{p} \quad (3)$$

whereas the flow equations:

$$Q=\mu\cdot K\cdot x\sqrt{p}+A_1\frac{dx}{dt}+\frac{V}{B}\frac{dp}{dt} \quad (4)$$

$$Q_p=\mu\cdot K\cdot x\sqrt{p}+A_1\frac{dx}{dt} \quad (5)$$

where:

$$K=\pi\cdot d_m\sqrt{\frac{2}{\rho}} \quad (6)$$

Equations of the valve work in the non-value form used to make simulation in accordance with work are shown in the following form:

$$\rho\frac{Q_o^{\ 2}}{A_1S_o}Q_{pw}^2+\frac{A_2\,p_o}{S_o}p_w+\frac{T_{Qp}}{T_o}\frac{dQ_{pw}}{dt_w}=1+\frac{kx_o}{S_o}x_w+\frac{T_f}{T_o}\frac{dx}{dt_w}+\left(\frac{T_{ms}}{T_o}\right)^2\frac{d^2x}{dt_w^2}+ \\ \Phi\frac{\sqrt{2\rho}}{S_o}\cos(v)Q_oQ_{pw}\sqrt{p_o}\sqrt{p_w} \quad (7)$$

$$Q_w=\mu x\sqrt{p_w}+\frac{T_A}{T_o}\frac{dx}{dt_w}+\frac{dp_w}{dt_w} \quad (8)$$

$$Q_{pw}=\mu x\sqrt{p_w}+\frac{T_A}{T_o}\frac{dx}{dt_w} \quad (9)$$

3.2. Importance of construction and/or exploitation parameters of the overflow valve

The model research is made in order to select important parameters which will ensure stable work to the real system. The specification of the importance of construction and/or exploitation parameters and then the selection of appropriate optimization procedure are crucial for the model verification. The changed construction parameters of the valve are as follows: *d* - valve diameter, *m* - valve head mass and *k* - spring constant – during the observation of *x* - elevation, *p* - pressure and Q - flow intensity. Exploitation parameters will introduce delays which during the application of inappropriate loop gain can cause unstable work of the system. In order to perform a discrete optimization, changes in parameters are encoded as follows: 0- big reduction, 1- small reduction, 2- no change, 3- augmentation, 4- big augmentation (for *m* and *k*) and : 0- small reduction, 1- no change, 2- augmentation (for *d*). As a result of simulation analyses made, 75 charts showing *x* - valve elevation, p - liquid pressure and Q – flow intensity have been gained for successive changes of parameters: *m*, *k* and *d*. In order to optimize, there is a dependency linking limits for construction and exploitation parameters [14]:

I. The stabilization time $t_w < 550 t_o$; the ratio of the maximum function value to its value after stabilization: $\frac{w_{\max}}{w_{stab.}}$ <2,4,

for the time course of x – elevation, *p* – pressure and *Q* flow intensity. In order to limit **I**, 25 charts have been chosen for which code changes of construction parameters *m*, *k* and *d* are shown in the table 1.

Tab. 1. KAPN for given changes of parameters *m*, *k* and *d* values

m	*k*	*d*	*m*	*k*	*d*
0	0	1	1	2	1
0	0	2	1	2	2
0	1	0	1	3	2
0	1	1	2	0	2
0	1	2	2	1	2
0	2	0	2	2	1
0	2	1	2	2	2
0	2	2	2	3	2
0	3	1	3	0	2
0	3	2	3	1	2
1	0	2	3	2	2
1	1	1	3	3	2
1	1	2			

It is necessary to notice that the criteria condition I does not allow the stability of the system work when *m*= 4, so the Table 1 presents only two canonical products (as true versions of designing guidelines), in which *m* parameter is encoded as: *0, 1, 2* or *3,* whilst the analysis of the valve work is for change (the valence of which is 5) in the code of the *m* parameter.

The SAPN of functions from the Table 1 is shown in the Table 2.

Tab. 2. SAPN of the function from the Table 1

m	*k*	*d*
0	1	—
0	2	—
0	—	1
1	1	1
1	2	1
2	2	1
0	—	2
1	—	2
2	—	2
3	—	2

The NAPN of functions from the Table 2 is shown in the Table 3.

Tab. 3. NAPN of the function from the Table 2

m	k	d	01-	02-	0-1	111	121	221	0-2	1-2	2-2	3-2
0	0	1			*							
0	0	2							*			
0	1	0	*									
0	1	1	*		*							
0	1	2	*						*			
0	2	0		*								
0	2	1		*	*							
0	2	2		*					*			
0	3	1			*							
0	3	2							*			
1	0	2								*		
1	1	1				*						
1	1	2								*		
1	2	1					*					
1	2	2								*		
1	3	2								*		
2	0	2									*	
2	1	2									*	
2	2	1						*				
2	2	2									*	
2	3	2									*	
3	0	2										*
3	1	2										*
3	2	2										*
3	3	2										*

After the application of the Quine – McCluskey algorithm, the NAPN and MAPN of a given logic function from the Table 3 is received: {01- ∧ 02- ∧ 0-1 ∧ 111 ∧ 121 ∧ 221 ∧ 0-2∧ 1-2∧ 2-2∧ 3-2}.

The Figure 2 shows exemplary charts of the functions *x*, *Q* and *p* for the code changes of parameters (*m*, *k* and *d*) *33*2 and *302.*

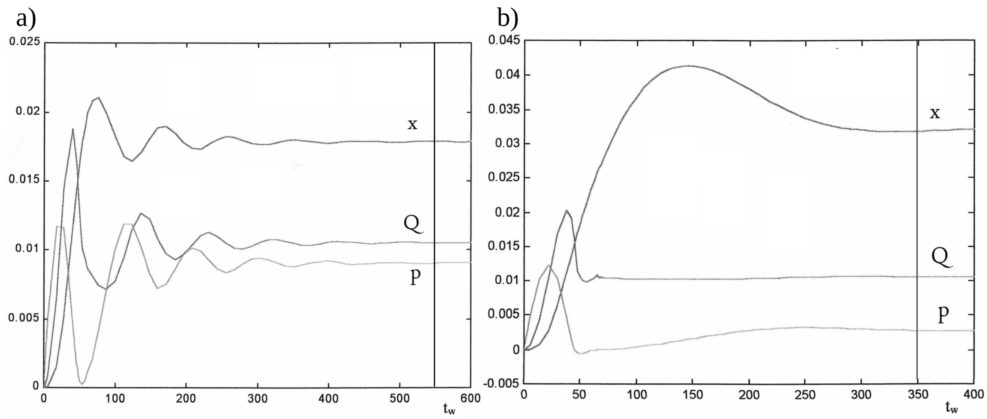

Fig. 2. Characteristics of the valve work for changes in the code of parameters *m*, *k* and *d: a)332, b)302*

3.3. Decision analysis of designing guidelines in the conditions of uncertainty in the analysis of dynamic properties of the overflow valve

During the changes of values of the construction and/or exploitation parameters it is possible that the whole system will be unstable whilst single parameters will be stable. If it is certain that the criteria conditions can be met only by some functions f_i from the set of functions f_r of a given system, then the optimization process takes place in the conditions of uncertainty.

For example, when introducing the criteria condition **II:** ($t_w < 1000 t_o$; $\frac{w_{\max}}{w_{stab.}}$ <3,6) some time courses (*x* – elevation, *p* - pressure *or Q* – flow intensity) are true simultaneously for the criteria condition **I** ($t_w < 550 t_o$; $\frac{w_{\max}}{w_{stab.}}$ <2,4)- for the same code changes of the parameters *m*, *k* and *d*.

Figure 3 presents the time course of the values *x*, *p* and *Q* (for the code changes *m*= 4, *k*= 0, *d*=2) , where the values *p* and *x* meet the criteria condition **II** and only the value *Q* meets the criteria condition **I**.

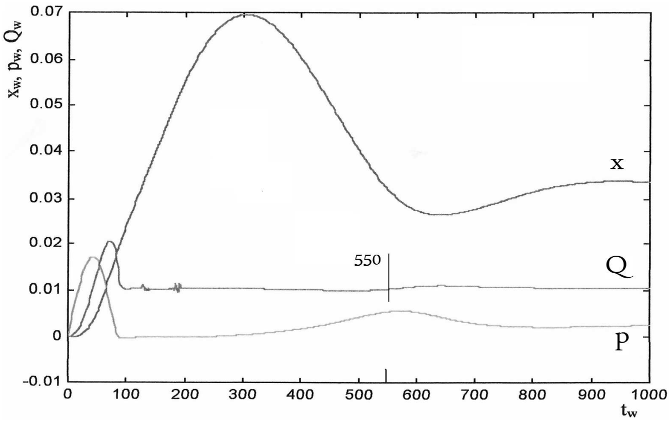

Fig. 3. Characteristics of the valve work for changes in code 402 (only *Q* meets the criteria condition I)

Figure 4 presents the time course of the values *x*, *p* and *Q* (for the code changes *m*= 0, *k*= 0, *d*=0) , where only the values *Q* and *x* meets the criteria condition **I** ($\frac{w_{\max}}{w_{stab.}}$ >2,4 for *p*).

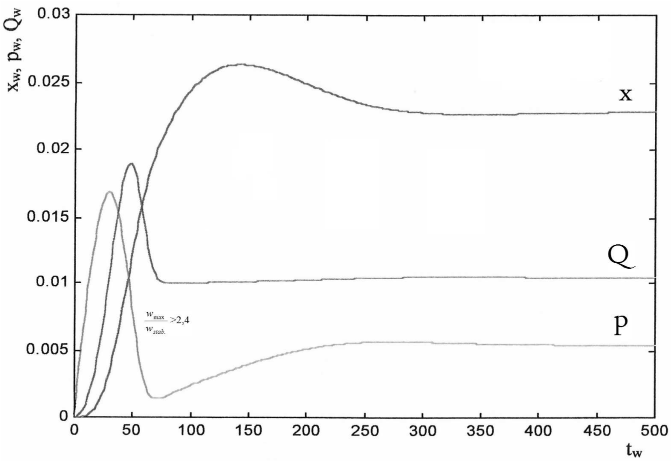

Fig. 4. Characteristics of the valve work for changes in code 000 (only *Q* and *x* meets the criteria condition I)

The canonical product of the changes in code values of parameters for which not all functions meet the criteria condition is called uncertain and is placed in parenthesis “( )”. Uncertain canonical products and the certain ones take part in the gluing process.

The Table 4 contains certain canonical products from the Table 1 and uncertain products describing changes in code for which only some time courses *x*, *p* or *Q* still meet the limiting criteria I with the change to the criteria II: (211), (201), (101), (422), (412), (000), (100), (402).

Tab. 4. KAPN for certain and uncertain changes in the value of parameters *m*, *k* and *d*

m	*k*	*d*	*m*	*k*	*d*
0	0	1	2	1	2
0	0	2	2	2	1
0	1	0	2	2	2
0	1	1	2	3	2
0	1	2	3	0	2
0	2	0	3	1	2
0	2	1	3	2	2
0	2	2	3	3	2
0	3	1	(2	1	1)
0	3	2	(2	0	1)
1	0	2	(1	0	1)
1	1	1	(4	2	2)
1	1	2	(4	1	2)
1	2	1	(0	0	0)
1	2	2	(1	0	0)
1	3	2	(4	0	2)
2	0	2			

The SAPN of functions from the Table 4 is shown in the Table 5.

Tab. 5. SAPN of the function from the Table 4

m	*k*	*d*
0	0	—
0	1	—
0	2	—
1	0	—
0	—	1
1	1	1
1	2	1
2	0	1
2	1	1
2	2	1
0	—	2
1	—	2
2	—	2
3	—	2
—	0	2
—	2	2
—	1	2

Tab. 6. NAPN of the function from the Table 5

m	k	d	m k d	0 0 -	0 1 -	0 2 -	1 0 -	0 - 1	1 1 1	1 2 1	2 0 1	2 1 1	2 2 1	0 - 2	1 - 2	2 - 2	3 - 2	- 0 2	- 2 2	- 1 2
0	0	1		*				*												
0	0	2		*										*				*		
0	1	0			*															
0	1	1			*			*												
0	1	2			*									*						*
0	2	0				*														
0	2	1				*														
0	2	2				*								*					*	
0	3	1						*												
0	3	2												*						
1	0	2					*								*			*		
1	1	1							*											
1	1	2													*					*
1	2	1								*										
1	2	2													*				*	
1	3	2													*					
2	0	2														*		*		
2	1	2														*				*
2	2	1											*							
2	2	2														*			*	
2	3	2														*				
3	0	2															*	*		
3	1	2															*			*
3	2	2															*			
3	3	2															*		*	
(2	1	1)																		
(2	0	1)																		
(1	0	1)																		
(4	2	2)																		
(4	1	2)																		
(0	0	0)																		
(1	0	0)																		
(2	0	2)																		

After the application of the Quine – McCluskey algorithm, the NAPN and MAPN of a given logic function from the Table 6 is received: {01- ∧ 02- ∧ 0-1 ∧ 111 ∧ 121 ∧ 221 ∧ 0-2∧ 1-2∧ 2-2∧ 3-2}.

Uncertain canonical products (211), (201), (101), (422), (412), (000), (100), (402) take part in the consensus process when forming the SAPN logic function, whilst they are not taken into consideration when looking for prime implicants of a given function (Table 6). As a result, the canonical products: 201 and 211 possess blank columns in the Table 6 (NAPN of a given function). Elementary products: 00-; 10-; -02; -22; -12 (earlier gluing in the SAPN of the function from the Table 5), possess a mark in one place thanks to uncertain canonical products that is they do not include all possible asterisks (*) in their columns (Table 6).

When taking into consideration uncertain changes in code, we get a higher number of elementary products gluing in the SAPN of the logic function (Table 5), whereas the MAPN form of the multi-value function from the Table 3 is equivalent to the MAPN for the Table 6.

4. Conclusion

The model analysis is made in order to select important parameters which ensure stable work to the real system. Due to the fact that phenomena occurring during the media flow are quite often described not precisely enough, it is often necessary to make an analysis in conditions of uncertainty. In the analysed example of the overflow valve work, the changing of the criteria condition **I** (rigorous) ($t_w < 550t_o$; $\frac{w_{\max}}{w_{stab.}}$ <2,4) to the criteria condition **II** (liberal) ($t_w < 1000t_o$; $\frac{w_{\max}}{w_{stab.}}$ <2,4) causes that the number of combinations of changes in construction parameters *m*, *k* and *d*, ensuring the stable work, increases. It means that the number of true versions increases that is the number of versions meeting optimization requirements for which time course of the analysed values *x*, *p* and *Q* simultaneously meet the limit II. However, it is possible to differentiate uncertain designing guidelines from the whole set of true solutions that is the guidelines for which some of the analysed values still meet the rigorous condition I. Such changes in the parameters code together with certain guidelines take part in the optimization process. Such a process makes it possible for the analysed functions to have an influence on the variables one by one. In this way, it is possible to get more information concerning the importance of the analysed parameters.

In the analysed example, the form of the MAPN of the multi-value function from the Table 3 is equivalent to the MAPN from the Table 6. However, it is necessary to highlight that for certain designing guidelines (Tab. 1) the valence of the *m* parameter is 4, whereas after taking into consideration uncertain guidelines its valence is 5 (Tab. 4). Moreover, there is too small number of uncertain guidelines in the analysed example. In a general case (removing the influence of the valence and increasing the number of uncertain products) it is possible to receive a smaller number of the most important designing guidelines.

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