STRUCTURAL IDENTIFICATION OF HEATING SYSTEM

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Abstract. *The main purpose of the paper is structural identification of heating system based, algorithm development. Two-circuit diagram example was used to obtain the most appropriate algorithm. Then, it can be used as a base for heating system structural identification.*

Keywords: algorithm, structural identification, heating system, modeling

STRUKTURALNA IDENTYFIKACJA SYSTEMU GRZEWCZEGO

Streszczenie. *Głównym celem pracy jest opracowanie adaptacyjnego algorytmu sterowania, bazującego na identyfikacji strukturalnej systemu ogrzewania. Do analiz użyto przykładowy schemat z dwoma obwodami. Zaproponowane rozwiązanie może być zastosowane jako podstawa do identyfikacji całego systemu grzewczego.*

Słowa kluczowe: algorytm, strukturalna identyfikacja, system grzewczy, modelowanie

Introduction

Technological development makes engineering systems more complex, and practical approaches to deal with such systems easily are requested. Regularly, these complex systems are usually consisting of a number of components, which are strongly related with each other and have wide range of input and output, and hence it is difficult to construct a global model applicable to the full range of input and output data set.

Heating system can be considered as a complex control plant. It ought to be characterized with nonlinear topological dependences between variables, nonstationary system elements parameters and changeable structure of heating system elements connections.

There are some difficulties during simulation modeling associated with changes of the heat network structure.

The main purpose of this document is to develop algorithm of structural identification of heating system.

1. Theoretical background

In control engineering, the field of system identification uses statistical methods to build mathematical models of dynamical systems from measured data. System identification also includes the optimal design of experiments for efficiently generating informative data for fitting such models as well as model reduction.

The structural identification means construction of object graph isomorphism and heating system model. This kind of identification covers structural part of heating system model [1, 2, 4, 5, 6].

The graph ispmorphism problem is given two graphs G1, G2 determine if there is a renaming of vertices of G1 which results in graph G2. Although it is not known if the general graph isomorphism problem can be solved in polynomial time, there are efficient sequantial and parallel algorithms for some classes of graphs [3, 6].

Generally, the need in structure identification depends on several parameters (factors) eg.: nonstationarity, and also current (rapid) changes of heating system (realized with connection and disconnection of heating system element).

Considered, topologically connected object is represented by initial oriented graph, where branches of V set are similarities of pipeline, heat exchanger and others elements of heating system, and assemblies of U set are flow connection and division elements.

Implementation of simulation based modeling algorithms using multiplex description graph representation has a number of advantages in comparison with matrix representation of system graph.

Thus, in considered case structural identification algorithms are written in the class of theoretical and multiplex description.

Assuming that initial graph is given by assembly set U and circuit set K reflecting diagrams of assembly and circuit graph branches connections, correspondingly.

System structure status is given by vector $L = \{l_i\}$, where $i \in N = \{1, ..., I\}$, l_i – can be 0 or 1, depending of connected or disconnected heating system elements [1, 2, 7, 8]. Set of assemblies U includes subset, v_i incident with assembly u_j, where $u_j = \{v_i,\ i \in N\}$, i – ordinal branch index, N – indicial number of branches, j – ordinal assembly index, $j \in M = \{1, ..., j\}$, M – indicial set of assemblies.

Circuit set K contains subset of branches v_i, included in independent circuits $k_v = \{v_i,\ i \in N\}$ of graph, where: v – ordinal circuit index, $v \in \Omega$, and Ω stands indicial sets of independent circuits.

Next, the task of structural identification is formed where current sets of assembly $\hat{U}$ and circuit $\hat{K}$ unambiguously defining subgraph of current heating system status are define from initial sets U and K and with known vector status K.

Offered algorithms for $\hat{U}$ and $\hat{K}$ determination, where $\hat{U} = A_u[U,L]$, $\hat{K} = A_k[U,L]$ are realized in class of opened identification.

A_u algorithm for $\hat{U}$ forms current assembly subsets U_s according to following rule:

Step 1. Status vector L analysis should be performed and in case of $l_i = 0$, elements with i index (branch v_i) are excluded from subsets $\hat{U}_s$, according to equation (1):

$$U = \{u_s : l_i = 0 \Rightarrow \hat{u}_s \Rightarrow \hat{u}_s \setminus v_i;\ s \in M, i \in N\}. \quad (1)$$

It is notable, that $\hat{U}_s$ subsets are formed being generated in accordance with L of main subgraph H_l.

Step 2. Subsets $\hat{u}_s$ are to be analyzed, and d assemblies degrees shall be defined. If degree of any of $\hat{u}_s$ assemblies is equal to 1 or 0, then subset $\hat{u}_s = 0$, regarding to equation (2):

$$U = \{u_s : d\{\hat{u}_s\} = 0{,}1 \Rightarrow \{\hat{u}_s\} = 0;\ s = \overline{1, J}\}. \quad (2)$$

In order to avoid possible occurrence of "suspended" assemblies in subgraph, step 2 is repeatedly applied till condition (3) is met:

$$\forall \hat{u}_s : d\{\hat{u}_s\} > 1 \quad (3)$$

A_k algorithm forms current circuit subsets $\hat{k}_v$ for $\hat{K}$ in accordance to the following rule:

If $l_i = 0$, then exclude from subset k_v elements with i indexes (branch v_i).

Artykuł recenzowany *otrzymano: 19.01.2012r., przyjęto do druku: 31.07.2012r.*

There are two options that can take place as a result:

– First option – v_i element belongs to two adjacent circuits of K initial set system, i.e. subsets k_v and k_z. Then, current set $\hat{k}_v$ is formed by joining of the initial subsets k_v and k_z, without element v_i, and current subset $k_z = 0$, according to equation (4):

$$\hat{K} = \{k_v : l_i = 0 \Rightarrow v_i \in k_v, k_z; k_v = k_v \cup k_z \setminus \{v_i\};\ v, z \in \Omega\}. \quad (4)$$

– Second option – v_i element belongs to one subset k_v that corresponds to the case with peripherical branch, then current subset $\hat{k}_v$ shall be defined simple reagarding to the equation (5):

$$\hat{K} = \{\hat{k}_v : l_i = 0 \Rightarrow v_i \in k_v;\ k_v = 0;\ v, z \in \Omega\}. \quad (5)$$

Obtained sets $\hat{U}$, $\hat{K}$ are describing current subgraph of status of heating system $\hat{H}$.

According to $\hat{U} = \{u_s\}$ and $\hat{K} = \{k_v\}$, whole system combined equations sets shall be reconstructed:

$$A \times \hat{Q} = \overline{\Phi}$$
$$B \times \overline{\Delta P} = \overline{\Delta P_H} \quad (6)$$

where: A – incidence matrix for assemblies of heating system graph, matrix elements a_{ij} can take value 0 or 1, and if $\hat{u}_s = \{v_\chi, \chi \in N\}$, $s = \{1, ..., J\} \Rightarrow a_{s\chi} = 1$; B denotes independent circuits matrix of heating system graph, with matrix elements b_{vi} can be values of 0 or 1, where: $\hat{k}_\alpha = \{v_\chi, \chi \in N\}$, $\alpha = \{1, ..., Y\} \Rightarrow b_{\alpha\chi} = 1$; $\overline{Q}$ – is vector of components, that are consumptions Q_i in system elements, and ΔP vector components are pressures $\Delta\rho_i$ at corresponding elements and $\overline{\Delta\rho_H}$ – vector of pressure period created by pumping equipment.

Obtained algorithm of structural identification allows to establish description current object status oriented subgraph. Upon that, orientation in branches shall correspond to orientation of initial graph.

2. Results

As an example that demonstrates proposed method of heating system identification, we shall consider initial graph of heating system represented at Figure 1.

It is given by the following U assemblies set (7):

$$U = \{u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8\} \quad (7)$$

where

$$u_1 = [v_1, -v_4];\ u_2 = [-v_1, v_2, -v_5];$$
$$u_3 = [-v_2, -v_6, v_3, \Phi_3];\ u_4 = [v_3, -v_7];$$
$$u_5 = [-v_4, v_8, -\Phi_5];\ u_6 = [v_5, v_9, -v_8];$$
$$u_7 = [v_6, -v_9, -v_{10}];\ u_8 = [v_{10}, v_7, -\Phi_2]$$

and circuits set K is described as (8):

$$K = \{k_1;\ k_2;\ k_3\} \quad (8)$$

where

$$k_1 = [v_1, v_4, -v_8, v_5];\ k_2 = [v_2, v_5, -v_9, v_6];\ k_3 = [-v_3, v_6, v_{10}, -v_7]$$

So that, correspondence vector L is given by:

$$L = \{l_1, l_2, l_3, l_4, 0_5, l_6, l_7, l_8, l_9, l_{10}\}. \quad (9)$$

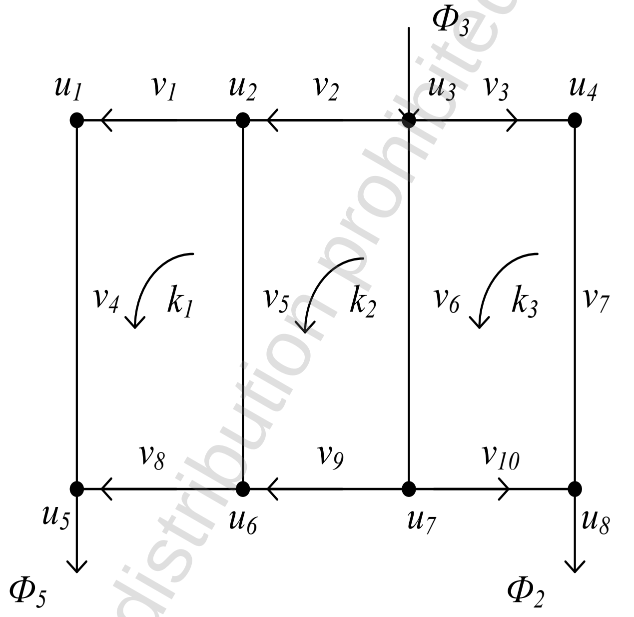

Fig. 1. Graph of considered heating system

Need to construct current assemblies U and circuits K sets defining subgraph of current object status.

Construction of U set, performed in accordance to (1), (2)

$$\hat{U} = \{\hat{u}_1; \hat{u}_2; \hat{u}_3; \hat{u}_4; \hat{u}_5; \hat{u}_6; \hat{u}_7; \hat{u}_8\} \quad (10)$$

where

$$\hat{u}_1 = [v_1\ -v_4];\ \hat{u}_2 = [-v_1, v_2];$$
$$\hat{u}_3 = [-v_2, -v_1, v_3, \Phi_3];\ \hat{u}_4 = [v_3, -v_7];$$
$$\hat{u}_5 = [v_4, v_8, v_3, -\Phi_5];\ \hat{u}_6 = [v_9, -v_8];$$
$$\hat{u}_7 = [v_6, -v_9, -v_{10}];\ \hat{u}_8 = [v_{10}, v_7, -\Phi_2];$$

Construction of set performed in accordance with rule (3), (4):

$$\hat{K} = \{\hat{k}_1 = [v_1, v_2, v_4, -v_6, -v_8, -v_9];$$
$$\hat{k}_2 = 0,\ \hat{k}_3 = [-v_3, v_6, v_{10}, -v_7]\} \quad (11)$$

Basing on obtained $\hat{U}$ and $\hat{K}$ sets, heating system material balance equation can be written using following equations (12):

$$Q_1 - Q_4 = 0;\ Q_2 - Q_1 = 0;$$
$$-Q_2 - Q_6 + Q_3 - \Phi_3 = 0;\ Q_3 - Q_7 = 0;$$
$$Q_4 + Q_8 - \Phi_5 = 0;\ Q_9 - Q_8 = 0;$$
$$Q_6 - Q_9 - Q_{10} = 0;\ Q_{10} + Q_7 - \Phi_2 = 0; \quad (12)$$

And balance of pressure period for heating system circuits

Circuit I: $\Delta P_1 + \Delta P_2 + \Delta P_4 - \Delta P_6 - \Delta P_8 - \Delta P_9 = 0$

Circuit III: $\Delta P_6 - \Delta P_3 + \Delta P_{10} - \Delta P_7 = 0$

3. Conclusion

The process of estimation involves the mathematical determination of unavailable or hard to access system states and uncertain parameters, using measurable states and a system model, that may be available in analytic form or may be derived recursively as a part of the estimation process. The diverse applications of estimation theory range from the design of state observers or parameter identifiers regarding to approach to the controlled system [5]. The key issue is to provide a suitable control problem solution as soon as possible.

Heating system can be considered as a complex control plant. It ought to be characterized with nonlinear topological dependences between variables, nonstationary system elements parameters and changeable structure of heating system elements connections.

Structure identification depends on several factors like nonstationarity, and rapid changes of heating system.

Two-circuit diagram example was used to obtain the most appropriate algorithm. Proposed algorithm of structural identification allows to establish description of current object status oriented subgraph. Upon that, orientation in branches shall correspond to orientation of initial graph and can be a basis for heating system structural identification.

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SPRAWOZDANIE Z WARSZTATÓW DOKTORANCKICH ORGANIZOWANYCH PRZEZ POLITECHNIKĘ LUBELSKĄ W DNIACH 09-11.07.2012

Warsztaty doktoranckie WD są konferencją naukową odbywającą się cyklicznie raz w roku, która skierowana jest do studentów studiów doktoranckich uczelni technicznych. Organizacja naukowego spotkania sprzyja wymianie doświadczeń i otwarciu dialogu w zakresie elektryki, elektroniki, automatyki, mechatroniki, bioinżynierii i informatyki. Tegoroczne warsztaty zorganizowano po raz trzeci dzięki inicjatywie Politechniki Lubelskiej, Instytutu Elektrotechniki i AGH.

Przez trzy dni (9-11 lipca) miasto Lublin było miejscem, gdzie studenci studiów doktoranckich z obszaru całego kraju brali udział w naukowym wydarzeniu.

Inauguracja tegorocznych warsztatów doktoranckich odbyła się w budynku Wydziału Elektrotechniki i Informatyki Politechniki Lubelskiej (fot. 1). Prof. dr hab. inż. Waldemar Wójcik, który pełni funkcje Dziekana Wydziału Elektrotechniki i Informatyki, otworzył "WD 2012" uroczystym powitaniem gości oraz przemówieniem, w którym poruszone zostały kwestie programowe. Głos zabrała także przyszła pani Dziekan prof. dr hab. inż. Henryka Stryczewska, której przypadła rola podziękowania gościom za przybycie i złożenia życzeń owocnej pracy podczas warsztatów.