FUNCTIONAL ANALYSIS

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Contents

Summary

Thermoeconomic Functional Analysis has been developed for analysis as well as for optimization of energy systems. It is considered that the system consists of units; each unit has one particular “function” (i.e. purpose or product), which is appropriately quantified. The interrelations between units or between the system and the environment are established by the distribution of functions. The units with the function distribution network are depicted in the functional diagram. The analysis gives the average unit prices and/or the marginal prices of the functions. Thus, the internal economy of the system is revealed.

Since the formulation is quite general (thermodynamics do not appear explicitly in the mathematical equations), it gave rise to further developments such as the ‘Engineering Functional Analysis’.

1. Introduction

The analysis of an energy system (e.g. a thermal power plant) is usually based on a flow diagram of the system, which consists of the components of the system and the streams of mater or energy connecting the components or the system with the environment. A different approach is the Functional Analysis, which has been developed initially for systems in general. Based on this approach and with rigorous application of mathematics and thermodynamics, the ‘Thermoeconomic Functional Analysis’ (TFA) has been developed as a method for analysis and optimal design or improvement of complex thermal systems (power plants, cogeneration systems, refrigeration plants, etc.).

Since the formulation of TFA is quite general, it was felt that its application could be extended to not only thermal, but other systems too. Thus, a further development of the method appeared under the name “Engineering Functional Analysis.” Furthermore, the approach of analysis presented in TFA has been used in the formulation of the “Structural Theory of Thermoeconomics.”

The functional analysis of an energy system reveals the internal economy of the system, helps in a better understanding of the interrelationships among the components, as well as between the system and the environment, leads to a rational cost allocation among the various products of a multi-product system, and, with the numerical values of certain indicators, shows the way towards improvement or optimization either of the operation or of the design of the system.

2. Concepts and Definitions

A thermal power plant or a chemical plant can be considered as a “system,” i.e. “a set of interrelated units, of which no unit is unrelated to any other unit” where “unit” is “a piece or complex of apparatus serving to perform one particular function” (in this case, apparatus is the system itself). It should be mentioned that a component of a plant (e.g. a condenser) may not necessarily be a unit of the system.

A system can be viewed also as a “time-varying configuration of men, hardware, and operating procedures grouped together for the purpose of accomplishing useful function(s).”

The word ‘“function” here has the following meaning: “Function, referable to anything living, material or constructed, implies a definite end or purpose that the one in question serves or a particular kind of work it is intended to perform.” Thus, “Functional Analysis” does not imply that particular branch of mathematics, but it is the formal, documented determination of the functions of the system as a whole and of each unit individually. However, Functional Analysis generates much more than just the functions themselves. The process of identifying and defining the functions produces the following results. It:

- leads to recognition of critical, important functions,
- reduces the probability of overlooking an important function,
- helps determine the interactions and relations of the functions,
- defines subsystems,
- is an aid for generating effectiveness and cost measures,
- enhances innovation,
- gives the designer an overall, diagrammatic model of the system,
- yields functional requirements which in turn lead to design requirements,
- clarifies constraints,
- provides documentation,

- is an aid for project scheduling,
- is an aid for determining system reliability and maintainability.

3. The Functional Diagram of a System

The picture of a system in this analysis will be composed primarily of the units represented by small geometrical figures, and lines connecting the units, which represent the relations between units or between the system and the environment. Since the relations are established by distribution of the unit functions, (i.e. ‘services’ or ‘products’), this picture will be called the ‘Functional Diagram’ of the system. Which direction a function (‘service’) goes is indicated by arrows on the lines.
In the functional diagram, each unit is shown as in Figure 1.

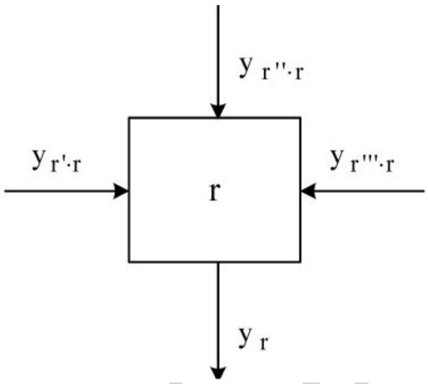

Figure 1. Unit.

The symbols in Figure 1 have the following meaning:

r	the r_{th} unit of the system ($r = 1, 2, ..., \sigma$);
y_r	the product, i.e. the appropriate quantitative description of the function of unit r;
$y_{r'\cdot r}$, $y_{r''\cdot r}$, …	functions used by unit r, which come from other units of the system or the environment; in particular, the environment is represented by r = 0.

It should be emphasized that a $y_{r'\cdot r}$ (a line with an arrow pointing towards a unit) does not necessarily represent a stream (of mass, energy, etc.) entering the unit. For example, exhaust gases of a boiler form a stream exiting the boiler, but the service of getting rid of exhaust gases is provided to the boiler by another unit. Similarly, if the boiler is to be penalized for environmental pollution, then the corresponding expenditure will depend on an appropriate measure of pollution, $y_{0k\cdot r}$, which is depicted as an arrow pointing toward the unit (the subscript 0k·r denotes the k_{th} function provided by the environment to the unit r).

There are cases where the functions of two or more units merge, and other cases where the function of a unit is distributed to more than one unit. They are represented by “junctions” and “branching points,” respectively (Figures 2 and 3).

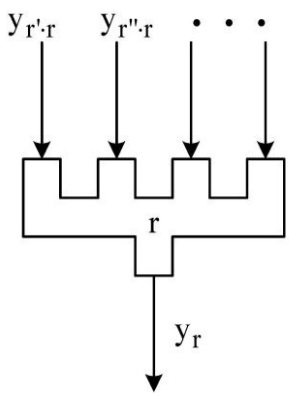

Figure 2. Junction.

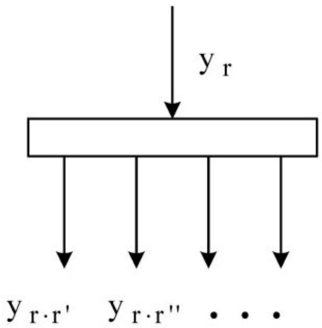

Figure 3. Branching point.

A junction or a branching point is considered a fictitious unit, except when it corresponds to a real component of the plant. The following relationships are applicable. For a junction:

$$\sum_{r'=0}^{R} y_{r'\cdot r} = y_r, \quad r = \sigma+1, \ \sigma+2, \ldots, R \qquad (1)$$

where R is the number of units and junctions. For a branching point:

$$y_r = \sum_{r'=0}^{R} y_{r\cdot r'}, \quad r = 1, 2, \ldots, R \qquad (2)$$

Using the rules established above, the functional diagram of a system can be drawn. The procedure will be demonstrated in the following section by a simple example.

4. Functional Analysis of a System

The functional analysis consists of two main actions:

- Identification of the functions of the system as a whole and of each unit individually.
- Drawing the functional diagram of the system.

Additional actions are needed, if optimization of the system is required (see Section 6). Instead of continuing in general but abstract terms, the procedure is more clearly demonstrated by a simple example.

A thermal power plant is considered, which consists of four units: a boiler, a steam turbine-generator, a condenser and a pump (Figure 4).

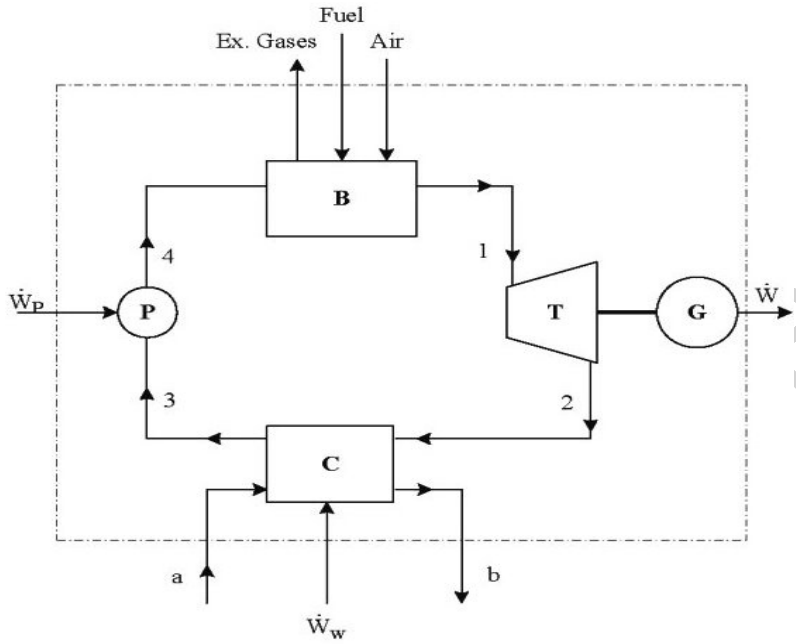

Figure 4. A four-unit thermal power plant. (B: boiler, T: steam turbine, G: generator, C: condenser, P: pump.)

It is appropriate here to distinguish between a unit and a component. A cooling tower or a cooling water circulating pump are components in themselves. However in this example, they are not considered as separate units but, combined with the condenser, they form only one unit, the function of which will be identified in the following section.

The number of units in a plant is not unique; it depends on the available information and the requested results. The designer will stay at a resolution level that is satisfactory for his objectives. He/she may go to a resolution level higher (more units), or lower (fewer units), if this serves his/her objectives better.

In order not to unnecessarily complicate the analysis, the following assumptions are made:

- the plant produces only electrical power at a specified rate $\dot{W}$,
- the power required by the pumps is supplied from outside the system,
- the components are well insulated,
- losses through the pipes connecting the components are negligible.

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Biographical Sketch

Christos A. Frangopoulos is Professor at the Department of Naval Architecture and Marine Engineering, National Technical University of Athens (NTUA), Greece. C. A. Frangopoulos received the Diploma in Mechanical and Electrical Engineering from the NTUA in 1971. After his military service (1971-1973), he worked as Superintendent Engineer of ship-owning companies, and as Head of the Diagnostic Center of a ship repairing company in Greece (1973-1979). He performed graduate studies in Mechanical Engineering with major in Thermal Sciences at the Georgia Institute of Technology, Atlanta, Ga., USA, leading to the M.Sc. degree (1980) and Ph.D. degree (1983). He joined the Department of Naval Architecture and Marine Engineering (NTUA) as a faculty member in 1985. He lectures on marine engineering, as well as marine and land-based energy systems in both undergraduate and inter-departmental graduate courses. His research activity is related to the development and application of methods for analysis, evaluation and optimal synthesis, design and operation of energy systems (power plants, propulsion plants, heat recovery systems, cogeneration systems, etc.) by combining thermodynamic, economic and environmental considerations. Second Law (exergetic) analysis and internalization of environmental externalities are two particular subjects of this work. He has often given invited lectures on the results of his research in several countries. Among his publications are more than forty papers in journals and international conferences and one book on cogeneration (in Greek).