Rankine cycle thermodynamic simulator of knowledge-based system for noise source identification of a steam power plant

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Dieser Artikel beschreibt die rechnerunterstützte Modellierung von Rankine-Kreisprozessen. Das dabei erzeugte IAPWS-Datenmodell kann für die weitere Berechnung der thermodynamischen Betriebsparameter bei Variationsrechnungen genutzt werden. Das IAPWS-Datenmodell ist ist besonders für die Modellierung von wasserbasierten Flüssigkeits- und Gasströmungen geeignet. Für die Simulation der akustisch relevanten Geräuschquellen in einer Dampfkraftanlage kann das Datenmodell für die Simulation des akustischen Anregungsverhaltens in Abhängigkeit von den thermodynamischen Prozessparametern eingesetzt werden. Die Grundlagen, Vorgehensweise und erste beispielhafte Ergebnisse werden in diesem Artikel vorgestellt.

This paper describes the design and development of knowledge-based system to assist thermodynamic calculation process of Rankine cycles. With this application, user can enter their Rankine cycle flow-diagrams and accompanying data into program. The knowledge-based system will then calculate various thermodynamic parameters which indicates the operating performance of the Rankine cycle. As the central of the knowledge-based system is the information/knowledge-base itself. The knowledge-based is designed by following Semantic Network model with frame-based representation. The knowledge-based system also features thermodynamic property data based on the IAPWS Formulation for General and Scientific Use (IAPWS-95). This formulation provides the most accurate representation of the thermodynamic properties of the fluid phases of water substance over a wide range of conditions available at the time this project was prepared. Since the noise source identification of steam power plan is started from the identification and calculation of the thermodynamic properties of the fluid phases of water substance over a wide range of conditions, so the knowledge-based system that supported the user to identification and calculation of the noise source of the steam power system.

1 Introduction

Power plants that use steam as their working fluid work on the basis of Rankine cycle. These include standing-alone steam power plants and those which are parts of combined cycle power plants. The first stage in designing these power plants is the thermodynamic analysis process of the Rankine cycle. In order to achieve optimal performance, the process is done repeatedly with various working conditions and modifications, which makes it a tiring and time-consuming job when done manually.

This paper describes the design and development of a computer program application which uses knowledge-based system principle to assist thermodynamic calculation process of Rankine cycles. With this application, users can enter their Rankine cycle flow-diagrams and accompanying data into program. The program will then calculate various thermodynamic parameters which indicates the operating performance of the Rankine cycle. These parameters include: thermal efficiency, backwork ratio, mass flow rate, power and work that is needed and produced by the cycle, heat transfer and its rate which entering and leaving system, and the working fluid states on each point in the cycle.

Several Rankine cycle modifications supported by the program include: superheat, reheat, regeneration, and supercritical Rankine cycle. The system supports regeneration with open feedwater heaters and closed ones with drains cascaded backward. For other Rankine cycle modifications that are not supported, the program provides steam-property retrieval facility, which can help users to retrieve thermodynamic properties of steam based on two known property values.

Noise source identification of steam power plan is started from the identification and calculation of the thermodynamic properties of the fluid phases of water substance over a wide range of conditions. The knowledge-based system supports the user to identify through black-box modeller and then to get the result of calculation of the steam power system noise source.

2 Basic Theories

2.1 Thermodynamics

There are three basic principles of Thermodynamics which are used extensively in every thermodynamic analysis. They are: the conservation of mass principle, the First Law of Thermodynamics, and the Second Law of Thermodynamics [1].

Conservation of mass for an open system requires that

$$\left\{\begin{array}{c}\text{Increase of}\\ \text{mass within}\\ \text{the system}\end{array}\right\} = \left\{\begin{array}{c}\text{Net amount of mass}\\ \text{crossing the boundary}\\ \text{into the system}\end{array}\right\}$$

The general statement of the First Law of Thermodynamics is an energy balance,

$$\left\{\begin{array}{c}\textit{Net}\\ \textit{increase}\\ \textit{in stored}\\ \textit{energy of}\\ \textit{system}\end{array}\right\} = \left\{\begin{array}{c}\textit{Net amount of}\\ \textit{energy added}\\ \textit{to system as}\\ \textit{heat and all}\\ \textit{forms of work}\end{array}\right\} + \left\{\begin{array}{c}\textit{Stored}\\ \textit{energy}\\ \textit{of matter}\\ \textit{entering}\\ \textit{system}\end{array}\right\} - \left\{\begin{array}{c}\textit{Stored}\\ \textit{energy}\\ \textit{of matter}\\ \textit{leaving}\\ \textit{system}\end{array}\right\}$$

The Second Law of Thermodynamics is a far-reaching principle of nature that has been stated in many forms. Two well-known statements of the Second Law of Thermodynamics are the Clausius statement and the Kelvin-Planck statement [1].

2.2 Rankine Cycle

A simple Rankine cycle consists of steam turbine, condenser, pump, and boiler (Figure 1). But in modern steam power plants, various modifications are usually incorporated to improve overall performance. Four modifications are presented in this project: superheat, reheat, regeneration, and supercritical Rankine cycle.

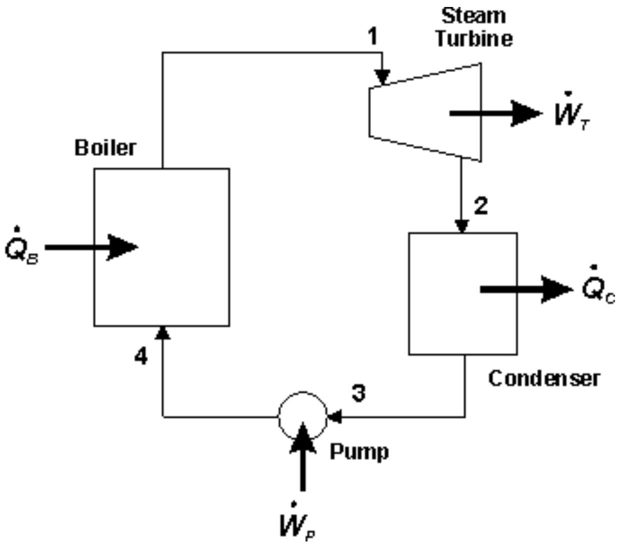

Fig. 1: Simple Rankine cycle

Superheat and reheat permit advantageous operating pressures in the boiler and condenser and yet offset the problem of low quality of the turbine exhaust [2].

Regeneration is the most commonly used method for increasing the thermal efficiency of steam power plants. Regeneration in Rankine cycle is accomplished by the use of feedwater heaters. Modern large steam power plants use between five and eight feedwater heating stages, and none is built without one. There are three types of feedwater heaters in use: open or direct-contact type, closed type with drains cascaded backward, and closed type with drains pumped forward [3]. Only the first two types are implemented in the program.

The supercritical Rankine cycle differs from the simple one in its steam-generator's pressure. Feedwater that enters the steam-generator is pressurized to a pressure beyond the critical pressure of the vapour (22.1 MPa for steam), hence there are no change in phase of the working fluid during the heating process [3].

2.3 Source of Thermodynamic Properties of Water and Steam

There are three sources, in the form of equation of states, of thermodynamic properties of water and steam used in this project. The first one is The IAPWS Formulation for General and Scientific Use (IAPWS-95) [4], which are used as the main equation of state for water and steam. The other two are used to support this equation of state. They are: The IAPWS Revised Supplementary Release on Saturation Properties of Ordinary Water Substance [5] and the one formulated by Thomas F. Irvine, Jr. and Peter E. Liley [6].

2.4 Numerical Methods for Solving System of Nonlinear Equations

In these project, systems of nonlinear equations are solved with Newton-Raphson method as described in [7]. This method is needed for reversing the IAPWS-95 equation of state. In its implementation, Newton-Raphson method requires additional numerical methods to solve system of linear equations and to calculate the first derivative of functions. These are accomplished by the use of Gauss Elimination and Centered Finite Divided Difference methods, respectively. These two methods are described in [8].

2.5 Knowledge-based System

Knowledge-based systems are systems which use knowledge and reasoning to arrive at conclusions [9]. One of the main features of knowledge-based systems is that the knowledge used by them is represented explicitly, rather than being implicit in the program code. In conventional programs it is only the data that is represented explicitly. In spite of this, however, knowledge-based systems are merely computer programs which have been written in a different way, in a deliberate attempt to isolate the various components of human (expert) problem-solving.

A knowledge-based system usually consists of three main components (Figure 2):

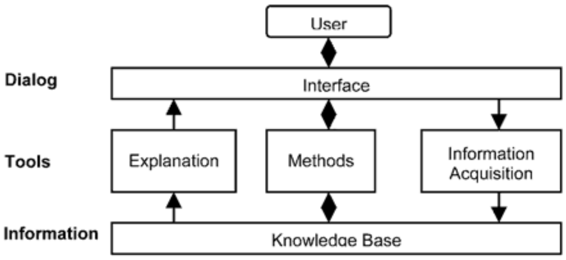

Fig. 2: Main components of a knowledge-based system

- Dialog, i.e. the user interface through which users interact with the knowledge-based system.
- Tools, i.e. an inference mechanism capable of transforming user requests into reasoned information using data from the knowledge-base.
- Information, i.e. the knowledge-base which contains facts plus information on how to reason with these facts.

The methods used to represent domain knowledge are central to knowledge-based systems. There are various methods available for this purpose, and one of them which is used in this project is Semantic Network model with frame-based representation [9].

3 Developing the Knowledge-Based

As the concept, the knowledge-based system should be able to support the user by building black-box what it's called as modeller, calculating the thermodynamic properties of the fluid phases of water substance over a wide range of conditions, then identifying and calculating the noise source of the steam power system (refers to figure3 below).

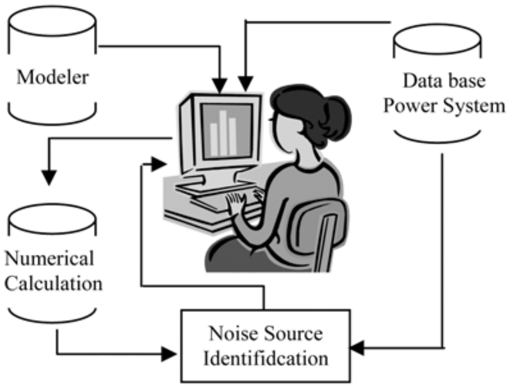

Fig. 3: Concept of knowledge-based system

The knowledge-based system is designed with object oriented programming approach, and is implemented with C++ programming language. Main components of the system is given in Figure 4.

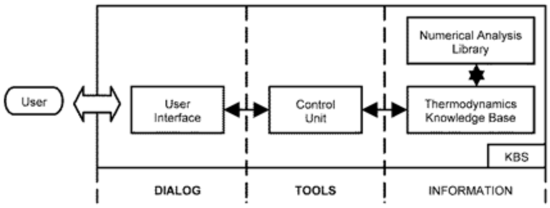

Fig. 4: Design of the knowledge-based system

As the central of the knowledge-based system is the knowledge-base itself, i.e. the Thermodynamics Knowledge Base. The knowledge-base is designed by following Semantic Network model with frame-based representation, which results in an abstraction or inheritance hierarchy, as shown in Figure 5.

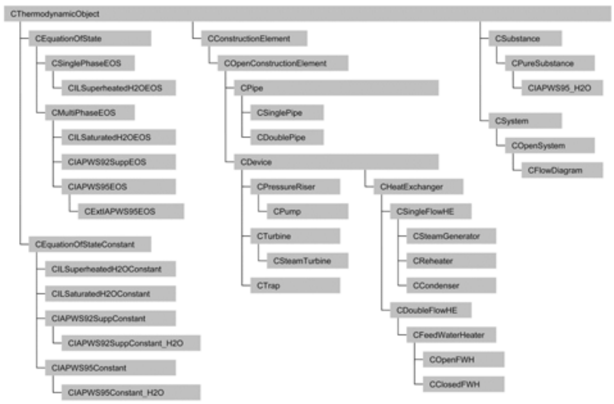

Fig. 5: Abstraction hierarchy of the knowledge base

The Numerical Analysis Library contains the three numerical methods explained above to support the knowledge base.

4 Discussion

Consider a reheat-regenerative vapour power cycle with two feedwater heaters, a closed feedwater heater and an open feedwater heater (Figure 6). Steam enters the first turbine at 8.0 MPa, 480 °C and expands to 0.7 MPa. The steam is reheated to 440 °C before entering the second turbine, where it expands to the condenser pressure of 0.008 MPa. Steam is extracted from the first turbine at 2 MPa and fed to the closed feedwater heater. Feedwater leaves the closed heater at 205 °C and 8.0 MPa, and the condensate exits as saturated liquid at 2 MPa. The condensate is trapped into the open feedwater heater. Steam extracted from the second turbine at 0.3 MPa is also fed into the open feedwater heater, which operates at 0.3 MPa. The stream exiting the open feedwater heater is saturated liquid at 0.3 MPa.

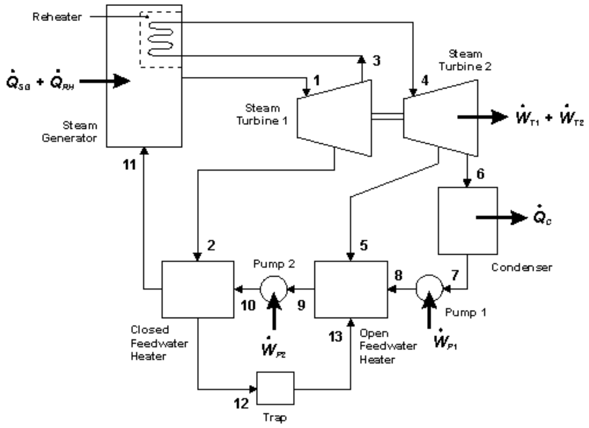

Fig. 6: Reheat-regenerative Rankine cycle

The net power output of the cycle is 100 MW. There is no stray heat transfer from any component to its surroundings. The working fluid experiences no irreversibility's as it passes through the turbines, pumps, steam generator, reheater, and condenser.

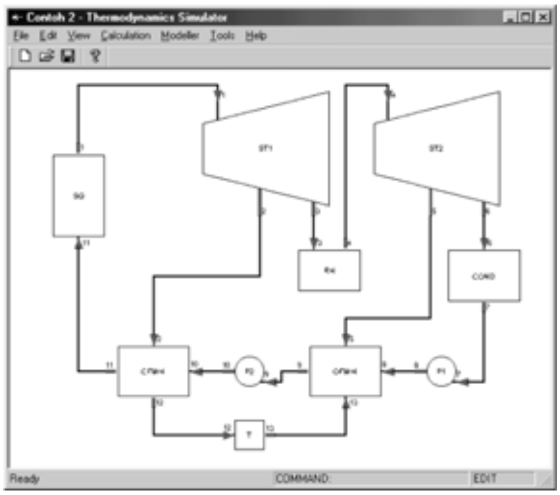

Fig. 7: Running program with the reheat-regenerative Rankine cycle diagram entered

Figure 7 shows the program user interface with considered Rankine cycle diagram and data entered. Scaled temperature-entropy (T-s) diagram of the cycle produced by the program is shown in Figure 8. Several parameters calculated by the program which indicate the operating performance of the Rankine cycle are:

Thermal efficiency	:	43.048 %
Backwork ratio	:	0.00654
Main mass flow rate	:	77.627 kg/s

Other parameters, including the operating conditions of the devices and the working fluid conditions at every point in the cycle, are calculated by the program, too. All of them can be viewed through the program's menus.

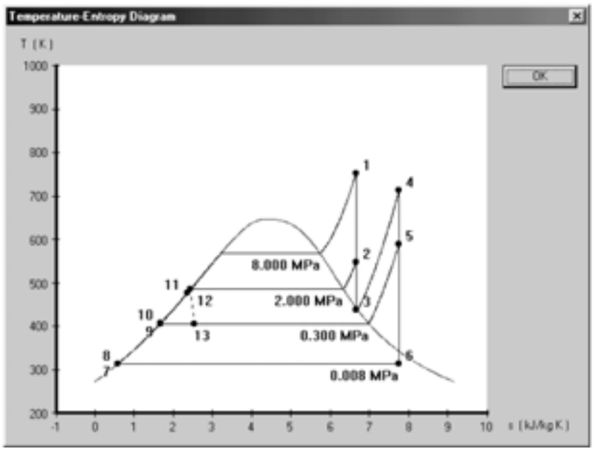

Fig. 8: Scaled T-s diagram produced by the program

Hence, the sound power level of system can be calculated through the calculation of each component which has at least one noise generation mechanism. All component which produce the noise, should be identified as noise source of the simulated steam power system.

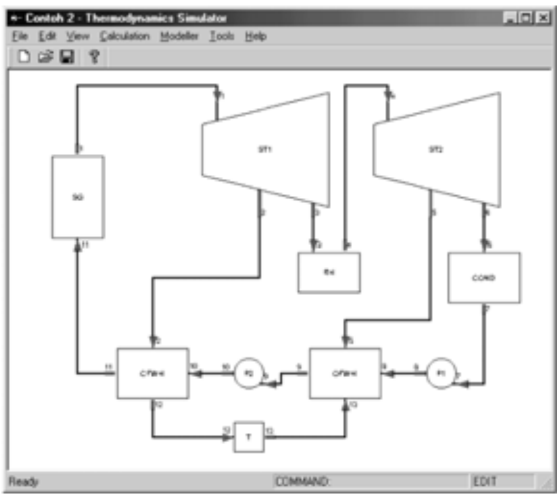

Fig. 9: Noise source identification

5 Conclusion

This project concentrates on the development of a knowledge-based system for solving thermodynamic calculations of Rankine cycles. With this computer program in hand, engineers can save time while designing Rankine cycles, which is usually the first design step in steam power plant design process.

Object oriented approach has been used in developing the knowledge-based system,, which makes it quite easy to add, remove, or change parts of the system in the future. This capability will be very useful when the information component, i.e. the knowledge base, need to be improved to be able to handle larger range of problems or more complex ones.

The knowledge-based system also features thermodynamic property data based on the IAPWS Formulation for General and Scientific Use (IAPWS-95). This formulation provides the most accurate representation of the thermodynamic properties of the fluid phases of water substance over a wide range of conditions available at the time this project was prepared.

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