# Simulation and Application of Auxiliary Machinery Systems for Seafarers Training

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**ABSTRACT**

The paper reviews the function of auxiliary machinery simulation system in a broad range of possible applications to the performance, evaluation of and training for marine operations. Main real time mathematical simulation models of auxiliary machinery systems are established. Typical performance failures and structural faults of auxiliary machinery systems were simulated. Interfaces and software programs of auxiliary machinery simulation system are designed and main functions and applications are briefly introduced.

## 1. Introduction

Along with rapid development of computerized and automated vessels all over the world, auxiliary machinery has been widely used on board ship. It is necessary to train engineers and crew to meet the operational requirements of modern ships with a lot of automatic control equipment. Elaborate and strict requirements for technology management, safety operation and emergency disposal have been defined in the international convention on Standards of Training, Certification and Watch-keeping for Seafarers in 1978, modified in 1995(STCW78/95) by the International Maritime Organization (IMO). Meanwhile, rules for marine simulator s training and evaluation were defined in considerable detail by Maritime Safety Administration of China (China MSA) in June 1998. It is a common sense that using marine simulator instead of a part of seafarer experience at sea can train modern senior officers rapidly and effectively. Auxiliary Machinery Simulation (hereafter AMS) system is an important sub-system of marine simulator.

## 2. Marine Auxiliary Machinery on Real Board Ship

In the past decades, progresses were numerous and rapid; remote and automated controls (with provision for local manual operation) operated from air-conditioned, soundproof compartments have come into common use. As these devices are now reliable, engine rooms are often unmanned for long periods. These changes have been naturally accompanied by some simplification of main systems, but have brought about a great increase in auxiliary machinery.

Auxiliary machinery covers everything on board except the main engines (or main boilers) and power station, and includes almost all the pipes and fittings as well as many items of equipment providing the following functions:

Supply the requirements of the main engines (or main boilers), for example: circulating water (include high temperature fresh water, low temperature fresh water and sea water), forced lubrication, fresh water generator, coolers, condensers, air compressors, oilfired and exhaust gas composite boiler, exhaust gas unit, fuel oil reception, transfer and treatment unit, etc.

Keep the ships dry and trimmed, for example: bilge and ballast systems.

Supply the domestic requirements, for example: fresh, salt, sanitary sewage systems, refrigeration, heating and ventilating system.

Moor the ship and handle cargo, for example: windlass, capstan, winches, steering engine, cargo-handling equipment and other special deck machinery.

Provide for safety, for example: fire detection and fighting, lifeboat engines and launching gear, watertight doors, etc.

Pollution protection, for example: oily water separator, sewage treatment unit and incinerator, etc.

Various duties of a marine engineer all relate to the operation of the ship in a safe, reliable, efficient and economic manner. A board-based theoretical and practical training is therefore necessary for a marine engineer. He must be a mechanical, electrical, air condition and refrigeration engineer, as the need arises. At his first voyage, maybe he does not at first realize that the essentials of certain arrangements do not vary greatly from ship to ship. After some experience he will find that he can familiarize himself in a strange ship quite rapidly, for example, bilge, ballast, fuel oil transfer, fresh water, sanitary water and other important systems.

AMS system is considered to be effective tools for the training of seafarers. Its importance is growing steadily, as more stress is being put on effective operational skills of the crews. To develop, improve and maintain the necessary skills and to test them, AMS at various levels of sophistication are used more and more frequently. AMS provides substitute shore-based operational environments in which the required skills can be developed, practiced and tested. It also contributes the cost-effectiveness, high capacity, emergency, fail-safety, intensity and controllability of training and testing, which are practically impossible to achieve under the job circumstances on board ship. Consequently, it became leading tools for the training of seafarers and for improving the safety and efficiency of marine operations.

### 3. AMS Mathematical Model

Auxiliary machinery systems, mainly made up of pipes and valves, etc., carries and controls the flow of a number of fluids at various, frequently varying, pressures and temperatures. The functions, requirements arising from ship construction, the nature and management of the machinery and regulations of certifying authorities, create situations in which systems basically simple, become complex and bring into use a variety of composing and fittings, which include pipes, valves, pumps, tanks, strainers, heat exchangers and controllers, etc.

(a) Tank s Level Equation

$$L_F(t) = L_{F0} - \int_0^t \frac{C_{FTVO}}{100} \cdot \frac{F_M(t)}{S_F} dt + \int_0^t \frac{C_{FTVI}}{100} \cdot \frac{F_{FP}(t)}{S_F} dt \tag{1}$$

Where,

$L_F$—fuel oil tank level, *m*;

$C_{FTVO}$—percentage of fuel oil tank outlet valve, *%*;

$C_{FTVI}$—percentage of fuel oil tank inlet valve, *%*;

$F_M$—reading of flowmeter, *kg/h*;

$F_{FP}$—discharge of fuel oil purifier, *kg/h*;

$S_F$—fuel oil tank area, $m^2$;

Other tanks level equations are not described.

(b) Valve Equation (HUANG Qinghong and HOU Xiaogang, 2001)

$$y_1 = (K_i dt + y_0) \cdot C_V \tag{2}$$

(c) Pump Equation (HUANG Qinghong and HOU Xiaogang, 2001)

$$y = F_M \cdot C_{PV} \tag{3}$$

(d) PID Controller Equation (HUANG Qinghong and HOU Xiaogang, 2001)

$$y_1 = y_0 + \left[ K_p(x_2 - x_1) + 1/T_i \int_0^t (x_2 + x_1)dt + T_d(x_2 - x_1 + x_0)/dt \right] \tag{4}$$

Where,

$K_p$—proportional gain;

$T_d$—differential time constant;

$T_i$—integral time constant.

(e) Oil Tank Temperature Alternation Equation

Here gives an example of diesel oil tank temperature calculation equation as

$$T_{DTK} = \frac{AT_{DTK0} + (BT_{40} - CT_{DTK0})t - \frac{(K_{5S} + K_5)T_{DTK0}t}{2} + (T_0K_{5S} + T_SK_5)t}{A + (B+C)t + \frac{K_5 + K_{5S}}{2}t} \tag{5}$$

Where,

$$A = L_{DTK0} S_{DTK} \rho_D C_D$$

$$B = (C_{22}C_{25}E_3Q_3 + C_{28}C_{29}E_2Q_2)C_{30}\rho_D C_D / 3600$$

$$C = (C_{34}Q_{DS} + C_{d2}Q_{d2})\rho_D C_D / 7200$$

$$K_5 = V_5 K_{50}$$

$$K_{5S} = \frac{L_5}{L_{5\max}} K_{5S0}$$

$$V_5 = \begin{cases} 1 & T_5 < 50 \\ 1 - \dfrac{1 - \dfrac{T_{5M} - T_0}{T_S - T_{5M}} \cdot \dfrac{L_5}{L_{5\max}} K_{5S0}}{T_{5M} - 50}(T_5 - 50) & T_5 \geq 50 \end{cases}$$

(f) Strainer Pressure Differential Equation

$$DP(t) = DP_0 + \int_0^t \beta F_M(t) C_{FVI} dt \tag{6}$$

(g) Heat Exchanger Equation (XU Xiaoyan, 2000)
Here gives an example of static model of surplus steam condenser as

$$t_w(t) = t_s(t) - \frac{1.16 g F_{FW}(t_{V2} - t_{V1})}{\alpha_m S_V} \tag{7}$$

Where,

$t_{VI}$—temperature of high temperature fresh water inlet in surplus steam condenser,_;

$t_{V2}$—temperature of high temperature fresh water outlet in surplus steam condenser,_;

$t_s$—saturation temperature of steam,_;

$t_w$—condensed water temperature at surplus steam condenser outlet,_;

$\alpha_m$ —mean coefficient for heat exchange of liquid film on pipe s surface, $W/(m^2.\_)$;

$S_V$—total area of pipe s surface for exchange heat, $m^2$;

$g$—the acceleration of gravity, $m/s$ ;

$F_{FW}$—high temperature fresh water s total flow, $m^3/h$;

(h) Simulation Algorithm of Mathematical Models
Quadruple order Runge-Kutta method is used in the algorithm of differential equation. Its basic idea is to pick up more nods such as n in the range of $x_i$, $x_{i+1}$ to predict their approximation slopes, and then weight and mean them as the approximation of average slope. A quadruple order Runge-Kutta format in common usage is shown as follow:

$$x_{n+1} = x_n + \frac{h}{6}(k_1 + 2k_2 + 2k_3 + k_4) \tag{8}$$

Where,

$h$ is the step.

$$k_1 = f(x_n, u_n)$$

$$k_2 = f\left(x_n + \frac{k_1}{2}, u_n + \frac{h}{2}\right)$$

$$k_3 = f\left(x_n + \frac{k_2}{2}, u_n + \frac{h}{2}\right)$$

$$k_4 = f(x_n + k_3, u_n + h)$$

The mathematical models of auxiliary machinery systems discussed in this paper have been realized by suitable algorithm in microcomputer. They have been confirmed by experiment and have obtained satisfactory result.

It is well known that more than 80 percent of accidents at sea are caused by human factors. The demands of computerized and automated vessels operations require that engineer should be taught more than the standard technical skills of their craft. Besides routine operations, AMS should also be executed under emergency situation or with some performance failures. This kind of training is very difficult to carry out on board ship and is therefore very economical in simulator training which can be of great benefit to seafarers calm emotion and strong ability dealing with the urgent situations. Over 100 typical performance failures of auxiliary machinery were simulated.

## 4. Development of AMS Software System

Development of AMS software system mainly realizes man-machine interfaces (hereafter MMI), models and communication of AMS. Generally, there are compressed air system, cooling water system, fuel oil system, lubricating oil system, oil-transferring system, oil purifying system, composite boiler system, incinerator system, bilge water system etc on board ship. In order to be convenient for operating and training, PID controller, system configuration and ITS (Intelligent Tutoring System base on expert system) are appended.

### 4.1 Development Environment of AMS Software

AMS software is the most important section with computer-based simulator system. In order to develop AMS software, the first thing is to select a development environment. It is a good selection to use Visual Basic integrated development environment and dynamic link library (DLL) of DAC system under WINDOWS operating system to develop AMS software (SHI Weifeng, 2002), because WINDOWS 9x/2000/NT operation system are widely used, and API functions called for WINDOWS can be used for multimedia developing of AMS. For example, sound simulation development of air compressor running and system alarming, picture or diagram simulation development of some man-machine interface. DLL functions called for WIONDOWS for DAC system is used for communication between AMS software and hardware. So digital signals and analog signals can be inputted and outputted.

### 4.2 The Network Structure of AMS

AMS system can be installed in personal computers (PC) with local area network (LAN) system based on WINDOWS 9x/2000/NT-operation system. The communication protocol of AMS system is TCP/IP protocol. AMS system is made up of some hardware and software. There are four sections of hardware system. The first section is microcomputer local area network (LAN) system, which is used for computer-based training (CBT) education of AMS. The second section is remote control console (RCC). The third section is dynamic mimic panel (DMP). The fourth section is simulated control consoles or boxes. They include fuel purifier control box, lubricating oil purifier control box, composite boiler control box, oily water separator control box and refrigerator control box, etc. The hardware includes data acquisition and control (DAC) equipment of industry microcomputer, which is made up of three parts as industry microcomputer, DAC interface and operation equipment. The structure of DAC is shown in Fig. 1. There are 20 computers which are used for trainees to learn basic operation of auxiliary machinery systems. There is one multimedia computer and overhead/data projector used for multimedia teaching of central classroom.

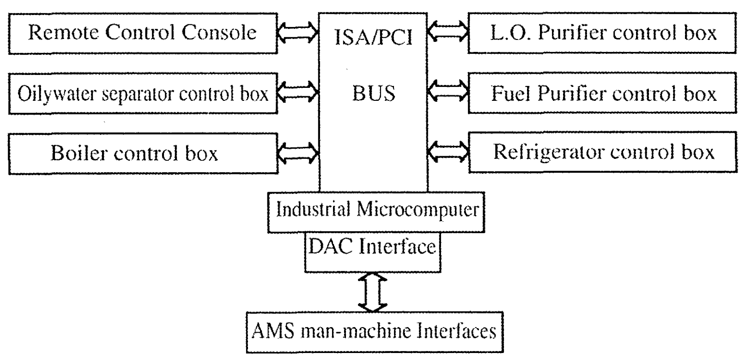
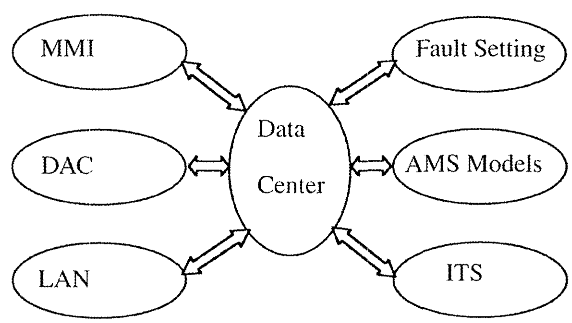



**Fig. 1** Data acquisition and control system

### 4.3 Software Structure of AMS

There are seven units in AMS software system. The first unit is data center unit of AMS system, and is shared by other six units. The second unit is auxiliary machinery models unit. Running conditions and dynamic process of auxiliary machinery systems are simulated in this unit. The third unit is software man-machine interface (MMI) unit, which is CRT operation interface of AMS. The fourth unit is DAC software unit, which is a connection unit between hardware and software. Switch signals and button signals of hardware are acquired. Parameters and display s status of AMS software are outputted through the DAC unit. There are functions of measurement value transform and functions of logic status encode or decode. The fifth unit is LAN



unit. Under WINDOWS operation system with TCP/IP network protocol, this unit is used to communicate among trainer s computer, trainee s computer and industrial computer of AMS. The sixth unit is fault simulation and setting. The seventh unit is ITS system, which is for trainee examination. The structure of AMS software is shown in Fig. 2.

### 4.4 Man-Machine Interface

Using Visual Basic integrated environment under WINDOWS operation system, a series of MMI were developed. Because many interface elements are offered by Visual Basic integrated environment, MMI of AMS software is very similar to real marine auxiliary machinery on board ship and can be made much more friendly with trainees, which is very important for AMS to be used in marine engine training and studying. There are 45 MMIs in the AMS software system. These MMIs mainly include configuration system, cooling water system, compressed air system, fuel oil system, lubricating oil system, composite boiler system, incinerator system, bilge water system, sewage system, fault setting system and ITS, etc.

## 5. Application of AMS

The performance of human operator cannot be separated from technical, organizational and other circumstances. Therefore, safety factors are intrinsically interrelated. To obtain insight into this mutual dependence and combined impact, it is necessary to be included in the evaluation of safety the human performer in his operational environment. As a result, owing to the complexities of the operation and essential role of the human task performer, the evaluation of risks cannot be adequately carried out and documented until operational experience and, unfortunately, the related casualty statistics support it (FAN Yongsheng, CHENG Fangzhen, etc., 2000).

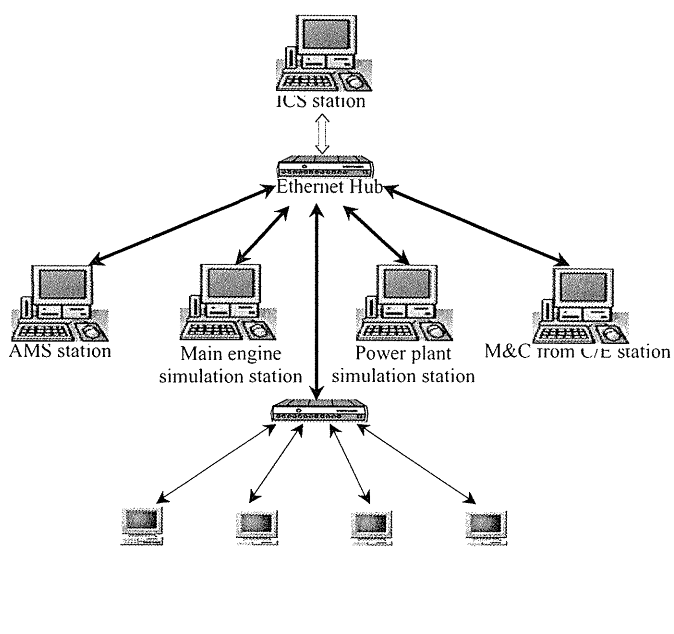
Intelligent Tutoring System (ITS) based on expert system is one of CBT functions. It can monitor and control trainees terminals on line. According to set status of AMS and selected items of trainer, one of experiment items will be produced by ITS. After that, trainee can begin his operating on software and/or hardware. ITS will record the operation step by step. The records include trainee s name, commenced time, completed time, position and contents of operating. According to correct rate of operation, ITS gives a score automatically. Result of operating will be printed through ITS station computer.

The functions of AMS were divided into two kinds: training function and evaluation function. Training function especially stresses controllable operation environment, physical and doing reality, abnormal condition to train trainees regulation operation and management, to master special operation method and process at some unusual conditions. Training program can be separated into four sections:

To lean layout and operation rules of auxiliary machinery on real board ship.
To operate and manage auxiliary machinery at normal conditions.
To operate and manage auxiliary machinery at emergency, dangerous and abnormal conditions.
To optimize operation and management of auxiliary machinery systems.

Evaluation function particularly emphasizes on trainee ability of operation, management and solving problems. AMS system can set some special operation condition, e.g. emergency dangerous and abnormal work condition to evaluate trainee s general ability. Alternation between trainer and trainee is also important in realizing trainer s controlling, monitoring, recording, evaluating and brief summary. AMS system can emulate most of failures or accidents of auxiliary machinery and reinforce seafarers ability to treat with emergency situations and reduce accidents due to human factor, which may have significant impact on the safety and efficiency of navigation at sea.

AMS system contacts with dynamic mimic panel, audio devices, local control console, remote control console, bridge control console, power distribution board, all kinds of control



boxes and some other hardware. It also communicates with other software systems via ICS station, such as main engine simulation system, remote control simulation system, power station simulation system, alarm simulation system, chief engineer monitoring & controlling system and instruction controlling system. According to instructor s commands from ICS station, AMS system can be operated in testing mode, isolation mode, online mode and offline mode (HU Xianfu, HU Yihuai and CHEN Baozhong 2002). Testing mode is used for self-checking of AMS system with standard data when necessary. In isolation mode, the software can be used as one of sub-system of the whole engine room simulator. Online mode is used for full-scale training of marine engine room (shown in Fig. 3). Any operation on hardware facilities can take effect upon all simulation systems. In offline mode, the software can only be used in personal computer without any hardware and other sub-system of marine engine room simulator. This mode can be realized in the 20-student-workstations where trainee can learn the operation rules and some background knowledge of auxiliary machinery.

Based on LAN, AMS system continuously obtains commands of running mode, ship navigating condition, time scale and failure code from ICS, receives main engine speed, main engine starting/stopping signal, main engine fuel rack, cylinder cooling water temperature, power supply of pumps and other control signals from main engine system, power station system and chief engineer (C/E) monitoring & controlling (M&C) system, sends out calculated results to main engine system, power station system, chief engineer monitoring & controlling system and alarm system. It gets user operation on hardware consoles and gives out digital parameters to hardware gauges and indicators. As mentioned above, the simulation system can emulate most of failures or accidents of auxiliary machinery systems which happen scarcely on board ship and reinforce seafarers ability to treat with emergency situations.

AMS system has been used in simulator training of marine engineers and can satisfy the requirement of related IMO conventions and codes.

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