

DOUBLE APPROACH MODELING OF TP- TABLE IN MASS FLOW-METER OF SUPERHEATED STEAM -Combined Application of Artificial Neural Network and System Identification

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Abstract : *In this paper a method based on combining Artificial Neural Network (ANN) training technique and Non-linear Least-square Linear in Structure System Identification technique for Double Approach Modeling the TP- Table in Mass Flow-meter is introduced. The model has several advantages such as saving calculation workload and storage space, having essential filterability of ANN Statistical Model. Thus the method provides a reliable way for realizing the current development for high- degree integration of measuring and instrumentation technology.*

Key Words: *Artificial Neural Network, Non-linear System Identification, Mass Flow Measurement*

1 INTRODUCTION

In the differential pressure type mass flow-meter for superheated steam the following equation is directly used for calculating mass flow of superheated steam in the pipe full of the steam^[1],

$$Q_m = [C / (1 - \beta^4)^{1/2}] \times \beta^2 \times d^2 \times (2 \times p \times \rho)^{1/2} \quad (1)$$

where Q_m is mass flow rate, β is expansibility factor of the steam p is differential pressure, ρ is density of the steam at line condition, C is discharge coefficient, d is diameter of the bore, β is ratio of d/D , and D is internal diameter of the pipe.

As well known that the value of ρ plays an important roll and is influenced by variation of temperature, T (k), and pressure, P (k), obviously. In some documents^{[1][3]} a table (called (T, P)- Table bellow) for finding proper value of density of steam under given temperature and pressure is provided. However such a table for normal range of industrial application includes a few hundreds of numbers which will need a few thousands of 8-bits registers, if expressed in 3- or 5- bytes flow point number form and stored in a E²PROM of a micro- controller system. Further more, the corresponding equation provided by IFC^[2] is so complex that it is impossible to be used in an instrument. So the problems of storage space and calculating workload happen and become a barrier facing the high degree integration technology.

In the following a model with high accuracy and simple structure for replacing the (T, P)- Table based on ANN (expressed below) and a statistical model is suggested and the method for setting up this model is illustrated.

2 ON-LINE OPERATING MODEL FOR (T,P)- TABLE AND ITS EQUATIONS

Through several experiments using different functional approach algorithms it can be determined that the functional relationship between T_c , P_c and ρ_c can be exactly described by the real-time model as eq. (2),

$$\rho_c = \rho_0 \times (p_c / T_c) \times K(T_c, p_c) \quad (2)$$

where T_c and P_c are on-line measured values of T and P , ρ_c is the corresponding density, ρ_0 is any beforehand given proper constant of density, K is a function of T_c and P_c . Equation (2) means that for any given reasonable values for a pair of T_c and P_c there should be a value of K , $K=K(T_c, P_c)$, which ensures that eq. (2) is valid.

Based on the fact mentioned above, a double model for (T, P) -Table can be set up by the way sketched out as follows:

Finding a model for function $K(T_c, p_c)$, called (T_c, p_c) - K model, and a model for function $\rho_c(T_c, K, P_c)$, called (T_c, K, P_c) - ρ_c model, a double approach model (called DA-model later) for calculating ρ_c from (T_c, P_c) is finally set up by combining both sub-models.

Based on the DA-model a process for calculating any value of ρ_c from given values for a pair of (T_c, p_c) , consists of following 2 steps:

First calculate the values of K using the (T_c, p_c) - K model and then calculate the corresponding value of ρ_c using the (T_c, K, p_c) - ρ_c model. The entire process is showed in Fig. 1, and the detailed modeling and calculating algorithm are described in the following paragraphs.

3 FUNCTIONAL APPROACH FOR (T_c, P_c) - K MODEL

Through any functional approach algorithm such as eq. (3) using sufficient groups of values, (T_c, p_c, ρ_c) , which are measured from the steam pipeline by using measuring instrument with high degree of accuracy or simulated by computer, the corresponding values of $K=K(T_c, p_c)$ can be calculated.

$$K_{i+1} = K_i f(\mathbf{r}_i - \mathbf{r}_i^*) \quad (3)$$

Equation (3) represents a calculating algorithm for approaching the values of K , where K_i and K_{i+1} are for the i th and $(i+1)$ th time calculated values of K , f is a factor through selecting which the converging speed is adjusted, \mathbf{r}_i^* and \mathbf{r}_i are density values, calculated and found out from the (T, P) -table for the i th time.

Then through the "learning and training algorithm" using the values of T_c , P_c and K a Fussy Inference Adaptive Artificial Neural Network (FIAANN)^{[4][5]} with 3 layers, 2 inputs and 1 output is set up which is used as (T_c, P_c) - K model as shown in Fig. 1 (Sub-model 1), where 2 input variables are T_c and P_c , and the output is $K(T_c, p_c)$.

The calculating algorithms represented by the model are illustrated in detail by literature [4] and [5].

4 SYSTEM IDENTIFICATION FOR (T_c, K, P_c) - ρ_c MODEL

Through the Gauss-Newton One Step Forecast Algorithm^{[6][7]} using sufficient groups of

$$y(k) = \sum_{j=1}^{10} a_j u_j(k) \quad (4)$$

values, (T_c, K, p_c) as inputs and c as output, a non-linear (linear in structure) model with 10 inputs and 1 output is identified shown as eq. (4) where $k=1,2,\dots$, are serial numbers represent the discrete times, $y(k)=c$ is output, $a_j, j=1,2,\dots,10$, are real constant parameters, $u_j(k), j=1,2,\dots,10$, represent $T_c, T_c^2, 1/T_c, P_c, P_c^2, 1/P_c, K, K^2, 1/K, T_c \times P_c \times K$ respectively. Eq.(4) plays the roll as model description for $c(T_c, K, p_c)$ shown in Fig. 1 (Sub-model 2).

5 COMPUTER SIMULATION TEST

200 groups of values of T_c, P_c and c are simulated by computer within the normal industrial application ranges, 433.15 (K) T 733.15 (K) and 400 (kp) P 1400 (kp), with the intervals, $|T| \leq 2$ (K) and $|p| \leq 5$ (kp). Using approach algorithm shown as eq.(3), 200 values of $K=K(T_c, p_c)$ are obtained accordingly. Based on the values $a(T_c, P_c)$ -K model with the FIAANN structure shown in Fig. 2 (as Sub-model 1 in Fig. 1) is set up through performing the algorithm described in paragraph "3" mentioned above repeatedly for sufficient times, where inputs T_c and P_c are changed artificially in a random way. Then using the values of T_c, K, P_c and c , a (T_c, K, P_c) - c model described as eq. (4) shown in Fig. 1 (as Sub-model 2) is set up through performing the algorithm described in paragraph "4" mentioned above for sufficient times, where inputs T_c, K and P_c are changed artificially in a random way. Finally the both sub- models are combined into a DA-model mentioned above.

To test the effect of the DA-model, 1000 groups of the values of T_c and P_c selected from the normal industrial range are entered into the DA-model, and the output, the corresponding values of c , can be obtained through the calculating algorithms represented by the DA-model mentioned in paragraph "3" and "4". Through sufficient times repeating this test process it can be seen that the maximum relative error of the output value of DA-model, compared with the (T, p) - Table offered in document [2] and with the calculated results based on the equations offered in document [3], reaches a value smaller than 0.1%.

To test the effect of the DA-model operated in a flow-meter the calculating algorithms of the model are programmed using assemble language of PIC16C77, the micro-processor produced by "Microchip" in USA, and fed in its peripheral memory, the E²PROM of type 24LC256. During the on-line experiment the DA-model is operated fluently and the maximum relative error of the output reaches a value smaller than 0.25% compared with the (T, p) - Table offered in document [2] and with the calculated results based on the equations offered in document [3]. So the DA-model could be adapted to a flow meter of the accuracy of 0.5%

6 EXTENDING APPLICAIION

The above mentioned modeling technology can be applied to replace the tables of enthalpy, and so on; and can be used to optimize the mass and volumetric flow-meter of different gases. This modeling technology is a very good tool for the development of modern sensor-conditioning-transmission integration technology.

7 CONCLUSION

The computer test experiment mentioned in paragraph "5" has shown that the double approach model for calculating c from given T_c and p_c , set up through the process mentioned in paragraph "3" and "4", can reach a high degree of accuracy so that it can be adapted to the flow meter with the accuracy of 0.5%. Further more, the calculation algorithm of the model has the considerable advantages such as saving calculating workload and storage space, reducing operation period and effective essential filterability.

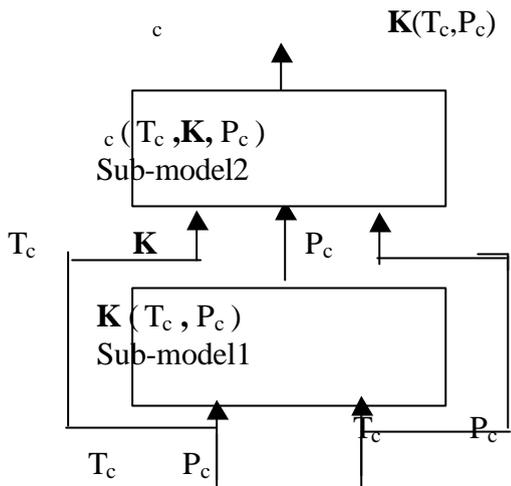


Fig. 1 Double Approach Model for Calculating from T_c and P_c

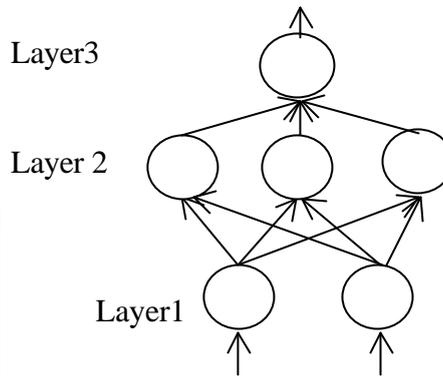


Fig. 2 Structure of FIAANN for $K(T_c, P_c)$ Model

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