Fifth IFSA World Congress (1993), 1199-1202

An Optimum Fuzzy Controller For Chinese Running Train

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ABSTRACT — An Optimum Fuzzy Controller which can be used to direct the driver to control a running train in an optimum operating way has been developed. In the development process of the controller, the theory and technology of Optimum Control and Fuzzy Control are applied. Practical field tests have been carried out in P.R.of China. In order to make the function of the controller more perfect, the controller is improved by the advanced fuzzy control technology and tool in Japan. The computer simulation of the improved controller has been finished.

1. INTRODUCTION

At present, with the rapid development of national economy, Chinese railway as a main and important transport way of long distance for passenger and freight bears a heavy pressure. In order to ensure the safety and punctuality of train's running, decrease fuel consumption and increase transportation efficiency, such a controller as shown in this paper is desired which can attain the objective mentioned above by realizing the train's optimum operation.

In the practical train's running, drivers control a train in various operating ways. Obviously, different operation will result in different running results including running time and fuel oil consumption and so on. But, in various operating ways, there must be a kind of operating way which running time is punctual and the fuel oil consumption is the least responding to the target enacted by official. Such a way is called an optimum operating way. Therefore it is necessary to decide an optimum operating plan with the help of some optimum theories concerned in locomotive diesel engine, drive mechanism and train's running. After obtaining the optimum operating plan, some control methods must be applied in order to realize the optimum operating way in the practical train's running. Here, Fuzzy Control is applied. In a word, the dominant thinking can be summarized as two points as:

(1) To decide an optimum operating plan off-line by Optimum Method, and
(2) To realize the optimum operating plan on-line by Fuzzy Control.

Table 1 shows some necessary data about the running train and running railway line.

2. SET UP AN OPTIMUM OPERATING PLAN

According to Reference [1], in the case of not considering some casual disturbances, the mathematic model of a train's running can be built as:

state equation: $dV/dt = 120C$ [km/hr/min] (1)

$dS/dt = V$ [km/hr] (2)

criterion: $J = \int_0^{tf} E(I, V)dt$ [litre] (3)

limit condition: $0 \leq S \leq Se$ [m] (4)

$0 \leq V \leq Vmax$ [km/hr] (5)

boundary condition: $S(0) = 0$

$S(tf) = Se$ [m] (6)

$V(0) = 0$

$V(tf) = 0$ [km/hr] (7)

where

V: train's running speed [km/hr]
Vmax: limit speed [km/hr]
S: running distance, Se: given distance [m]
t: time, tf: given time [min]
I: control handle position [grade]
E: unit fuel oil consumption [litre/hr]
C: compound traction force [kgf]

To solve such a non-linear and dynamic two dimensional optimum problem with limit condition, the Direct Net Optimum Search Method[2] is used based on the following considerations:

(1) E is a hidden function of I and V and its value can be obtained only by test curves. Thus, a direct optimum method is suitable.
(2) This method features simple calculation, obvious direct character, no special request to criterion function and no complicated mathematic deduction in application. And it is fit only for low dimension problem.
(3) The solution by this method is compared in the whole search region when calculated,

thus, the difficulty of solution discussion on single and existent character is removed.

Whole optimum search process is fulfilled by the computer and its software is programmed in FORTRAN77. When deciding some optimum factor such as the positions and the change times of control handle, the standard of running time and the fuel consumption of different running ways, the optimum theory of the diesel engine and drive mechanism of a train and experience of some skilled drivers are fully considered in this program. The final calculated result is the optimum operating plan and it is saved and printed out in a data table form[2]. After the data table is converted into hexadecimal number and memorized in an EPROM, the optimum operating plan is all right to be applied in practice. As an example, the optimum operating plan from KaiFeng Station to XingLongZhuang Station is shown in Figure 1 in a curve form.

3. DESIGN OF THE OPTIMUM FUZZY CONTROLLER

As mentioned above, some casual disturbance is not considered at all while building the mathematic model. But in real train's running, there are many casual disturbance factors. And, the calculated result off-line is not the same as a real train's running after all because there always exist some calculating errors. Therefore, an effective control method must be used to ensure a train to run in the optimum operating way even under some casual disturbance. Here, we think:

(1) On the optimum operation, the given values in the optimum operating plan change at all times and all place. The problem is how to make the train trace the optimum operating plan closely. Therefore, it is not fit to use some conventional control methods.

(2) In a real train's running, many disturbance factors are casual and have not regularity, so it is impossible to build a satisfactory mathematic model of an real train's running on-line. It seems impossible to solve this problem by conventional control methods.

(3) Though these casual disturbance factors can not be exactly predicted, a skilled driver can take some reasonable control actions to have the train run normally with the help of his extensive operating experience.

(4) It may be suitable to realize the optimum operation of a running train by utilizing a fuzzy controller which uses the most likely control rules based on extensive experience of skill drivers and the control effect may be good.

Therefore, the fuzzy control is applied to realize the optimum operating plan on-line.

The state variables describing a train's running are running speed, running time and others. The following special factors about a train's running should be considered:

(1) The inertia of a train's motion is larger and its speed change is relatively slow.

(2) Since the punctuality of a train's running must be kept, a great attention should be paid to the running time.

Moreover, other state variables have been properly thought over in the optimum search process. Thus, speed error ΔV and time error ΔT are taken as the inputs of the Optimum Fuzzy Controller. ΔI is taken as the output of the controller which is called a revising control handle position. ΔV, ΔT and ΔI and their values region are:

$$\Delta V = Vr - Vo, \quad [-6, +6] \quad [km/hr] \qquad (8)$$

$$\Delta T = To - Tr, \quad [-1.5, +1.5] \quad [min] \qquad (9)$$

$$\Delta I = Ir - Io, \quad [-2, +2] \quad [grade] \qquad (10)$$

where

Vr: practical train's running speed

Vo: desired speed in the optimum operating plan

Tr: practical train's running time

To: desired time in the optimum operating plan

Ir: a real control handle position that the driver should use at real-time

Io: a desired control handle position in the optimum operating plan

The fuzzy sets A, B and C is respect to ΔV, ΔT and ΔI. The Normal Distribution function is used to describe membership function of A and B because this distribution is similar to the style of mankind thinking. The form of the fuzzy reasoning is:

$$\text{IF } \Delta V = Ai \text{ AND } \Delta T = Bj \text{ THAN } \Delta I = Ck \qquad (11)$$

Considered on the characteristic of the train's running, referenced in the conventional fuzzy inference principle and based on experience of skilled drivers, fuzzy reasoning rules can be obtained as shown in Reference[3]. Other fuzzy calculating formulae are:

$$\text{Fuzzy Relation:} \quad R = \bigvee_{i=1,\, j=1}^{i \times j = 49} (Ai \times Bj)T \times Ck \qquad (12)$$

$$\text{Fuzzy Composition:} \quad C = [(A \times B)^T] \cdot R \qquad (13)$$

$$\text{Fuzzy Decision:} \quad Cmax = \Sigma (Ki \cdot Ci) / \Sigma Ki \qquad (14)$$

where, the Weighted Average Method is used for fuzzy decision and Ki is the weight parameter to be equal to the membership: $Ki = \mu(Ci)$. By these fuzzy calculations, a real-time control table used in practice is obtained as shown in Table 2. This table is saved into an EPROM of the microcomputer system used for the Optimum Fuzzy Controller. When the train runs, Vr and Tr are measured at the fuzzy control point and then compared with the values Vo and To of the optimum operating plan. By equations (8) and (9), ΔV and ΔT can be got. After that, ΔI can be decided by a program of inquiring the real-time control table. Then the optimum control handle position Ir that train's driver should use at that time can be calculated by equation (10) and displayed on-line. Therefore, as long as the driver controls the train according to the instruction of the controller, the train's optimum operation is able to be realized.

4. REALIZATION AND FIELD TEST OF THE CONTROLLER

The hardware sketch of the Optimum Fuzzy Controller is shown in Figure 2. Such a microcomputer system has the following functions on-line.

(1) Measuring various signals through relevant

sensors and dealing with these signals.

(2) Setting up an real-time clock, doing various calculation, dealing with various data and judging the fuzzy control point.

(3) At the fuzzy control point, calculating ΔV and ΔT, reading the real-time control table according to the real situation, displaying Ir and directing the driver to control the train in the optimum operating way.

(4) All running parameters and results can be displayed on-line alternately. The data are all recorded and memorized automatically. The data can be printed by the microprinter after the train stops.

(5) On the driver lost the control ability for the running train in front of the red light signal, the controller can take an emergency brake to ensure safety of the train.

From November of 1987 to March of 1988, practical field tests of the Optimum Fuzzy Controller were carried out on Beijing Type Diesel Locomotive No.3329 in Zhengzhou Railway Ministry, Henan, China[4]. The test result from KaiFeng Station to XingLongZhuang Station on November 11, 1987 is also shown in Figure 1. Other test results are shown in Reference [3]. The test results show that under the direction of the Optimum Fuzzy Controller, the driver can control the train in an optimum operating way roughly. The train's running is punctual and fuel oil can be saved by about 16.67% relative to the fuel oil consumption target enacted by official. The test result in Figure 1 is above the average operating level.

5. IMPROVEMENT OF THE OPTIMUM FUZZY CONTROLLER

Though there are many disturbance factors in the practical train's running, the slope grade and the climate affects train's running greatly. In order to consider the effect of wind and slope, by use of OMRON FS1000[5] which is a kind of fuzzy control software, two more inputs are added to the original controller. The name of four inputs is afresh defined:

$$SV(\Delta V) = Vr - Vo \quad [km/hr] \quad (15)$$

$$ST(\Delta T) = To - Tr \quad [min] \quad (16)$$

$$SC(Climate) = \text{Wind Grade} \quad [grade] \quad (17)$$

$$SS(Slope) = \Sigma(Si \cdot i) / \Sigma Si \quad [‰] \quad (18)$$

$$SI = Ir - Io \quad [grade] \quad (19)$$

where, the meaning of Vr, Vo, Tr, To, Ir and Io is the same as those in equation (8), (9) and (10). Si is the slope length of every slope between the fuzzy control points and i is slope grade with respect to Si. Output is still a revised control handle position that is renamed as SI. In order to increase the range of regulation, its value range becomes to [-3, -2, -1, 0, +1, +2, +3] now.

The form of the fuzzy reasoning is:

IF SV=TVE AND ST=TTE AND
SC=CWE AND SS=SRE THEN SI=RCH (20)

where TVE, TTE, RCH $\in$ [NL, NM, NS, ZR, PS, PM, PL],
and CWE, SRE $\in$ [NL, NS, ZR, PS, PL].

The improved controller consists of a set of fuzzy reasoning rules on considerations as:

(1) The extensive operating experience of skilled drivers are used.

(2) The situation of climate and slope which is often met in the practical operating is only thought.

(3) Limited by the maximum 128 rules of OMRON FS1000, simplicity and realization are taken as a principle, so 49 rules are selected.

In the membership functions of TVE, TTE, CWE and SRE, triangle-like fuzzy numbers are used with conventional definition methods[5]. But the value range of the fuzzy number ZR in CWE is set wider as shown in Figure 3, because when wind is less than 3 grade, wind effect for the train's running is smaller.

6. SIMULATION OF THE IMPROVED CONTROLLER

The performance of the improved controller is simulated in order to check whether it is designed properly. The data in OMRON FS1000[5] as a set of imitation input is used. Continuous fuzzy reasoning is done by the controller. The result of simulation is given in Figure 4.

The practical running simulation is taken under such actually given conditions as shown as Table 1. The simulation result, together with the optimum operating plan and the field test points by the original controller, is given in Figure 1. The simulation result shows: at the first fuzzy control point, the train's running speed largely differs from that of the optimum operating plan because it is assumed that the train's running met some great disturbance. At the second fuzzy control point, looked superficially, the simulation result by the improved controller is not good but, in fact, at the third fuzzy control point, the simulation result is almost the same as the optimum operating plan. In present simulation, although the train meets strong disturbance, it still can run roughly in the optimum operating way under the direction of the improved fuzzy controller. The running time is 15.68 [min] punctually.

7. CONCLUSION

(1) The Optimum Fuzzy Controller is a train carried-on microcomputer system which is able to direct a driver to control a train in an optimum operating way. The practical field test results show that the train's running is punctual and the saving fuel oil effect is obvious. It can be sure that the Optimum Fuzzy Controller is a kind of microcomputer control system with a bright prospect in Chinese railway.

(2) The Figure 4 indicates that the design of the improved Optimum Fuzzy Controller is reasonable and the control rules are right, otherwise such standard wave form can not appear[5]. In the simulation of a practical running, although it is assumed that train's running deviates from the optimum operating plan at the first fuzzy control point, the train can still run roughly in the optimum operating way under the direction of the improved controller. Therefore, the control function of the improved controller seems stronger. If condition allows, a practical field running test should be carried out in P.R. of China again.

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[4] Optimum Operating Device for Train's Running, reported in Renmin Daily Newspaper(人民日報"), Beijing, P.R.of China (March 11, 1988)

[5] OMRON: Software FS1000 Instruction Book, OMRON Corporation, 9-10,58-75, Japan (1991)

Table 1. Some Necessary Data

Beijing Type Diesel Engine Locomotive Rate Power: 2700 [horsepower] Driving Way: Hydraulic Drive Main Function: Traction of Passenger Train Control Handle:0 to 16 [grade]
Running Data Train: Common Passenger Train 448, 14 Cars, Stop at 23 Stations Section: ZhengZhou to ShangQiu, LongHai Line, Henan, P.R. of China Distance:199.75 [kilometer] Time: 300 [minute] (Stop Time Included) Fuel Target: 637[liter]
Practical Example in This Paper Station: KaiFeng to XingLongZhuang Distance: 15000 [meter] Time: 15 [minute] Fuel Target:48 [liter]

Table 2. Real-Time Fuzzy Control Table

⊿I	⊿V												
⊿T	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6
-1.5	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+1	+1
-1.3	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+1	+1
-1.0	+2	+2	+2	+2	+1	+1	+1	+1	+1	+1	+1	0	0
-0.8	+2	+2	+2	+2	0	0	0	0	0	0	0	0	-1
-0.5	+2	+2	+1	+1	0	0	0	0	0	0	0	-1	-1
-0.3	+2	+2	+1	+1	0	0	0	0	0	0	0	-1	-1
0.0	+2	+2	+1	+1	0	0	0	0	0	-1	-1	-2	-2
+0.3	+2	+2	+1	+1	0	0	0	0	0	-1	-1	-2	-2
+0.5	+2	+2	+1	+1	0	0	0	0	0	-1	-1	-2	-2
+0.8	+2	+1	+1	+1	0	0	0	0	0	-1	-1	-2	-2
+1.0	+1	+1	0	0	0	0	0	-1	-1	-2	-2	-2	-2
+1.3	+1	+1	0	0	0	0	-1	-2	-2	-2	-2	-2	-2
+1.5	+1	+1	0	0	0	0	-1	-2	-2	-2	-2	-2	-2

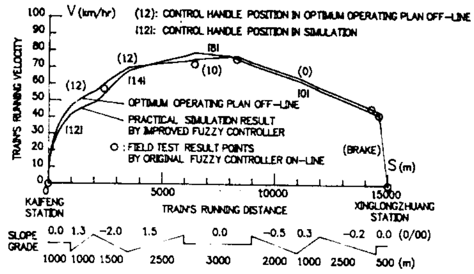

Figure 1. Practical Running

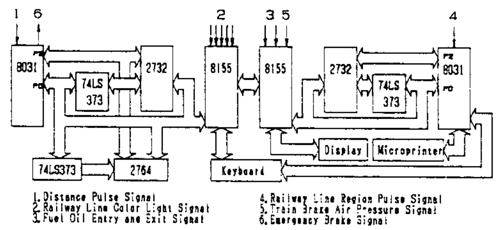

Figure 2. Hardware Sketch

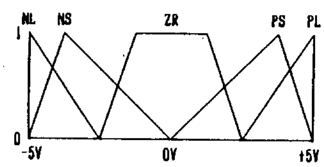

Figure 3. Membership Function Of CWE

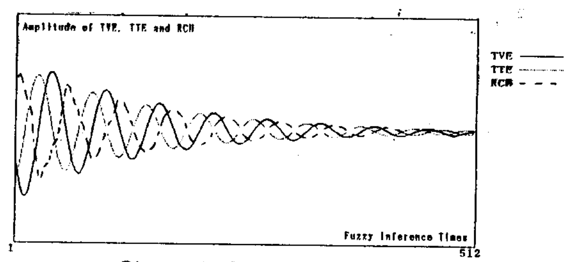

Figure 4. Performance Simulation