Drives for High Speed Railway Traction: A Neuro-Fuzzy Logic Controller for Friction Force

SALVATORE PENNACCHIO, FRANCESCO MARIA RAIMONDI
Dipartimento di Ingegneria dell'Automazione e dei Sistemi
Università degli Studi di Palermo
Viale delle Scienze, cap 90128, Palermo
ITALY

Abstract: - This paper presents a fuzzy logic controller for the control system of the friction force in the high-speed trains. Friction force is necessary for reduction of skidding phenomena. It is possible to transmit the maximum traction effort to the wheel and to have the relative maximum speed only with an optimal control system for the friction force. The value of friction force is under uncertain situations and it depends on many factors. This paper introduces a fuzzy logic approach for the control system of friction force in high speed railway. This kind of approach has been chosen because the fuzzy logic controller is capable of making inferences even under uncertainty. The results have been obtained with a simulator of an italian high speed train the FS ETR500 and they demonstrate that a train can run at an high speed with minimum skidding phenomena.

Key-Words: - High speed railway, fuzzy logic, control system.

1 Introduction

The main goals of several researches in the field of high-speed railway are based on: improving of a quality of service for passengers and increasing productivity. Therefore high-speed trains must be reliable and with an optimal anti-skid control strategies. The new high-speed trains are created for transmitting the maximum traction to the wheel. This situation has created new problems, in the field of railway, based on the adhesion and the skidding phenomena [1].

First of all it is necessary an analytical study of physical phenomena related with the high-speed trains and then it is possible to consider the related problems.

A control system for reduction of skidding must consider: a quickly detecting of a skidding, a control system for reducing of torque during skidding. An high power occurs for an high-speed train and a bad transmission of this power could concern an high dissipation of energy. It is important a total adhesion between the wheel and the track.

High-speed railway is different from normal railway and then the research approach is different.

An adhesion characteristic of different trains has been studied in [2,3]. It has been made a study on the induction motors in order to increase the adhesion when there is the sliding.[4,5].

The instantaneos loss of adhesion between the wheel and the truck is equivalent to an impulsive solicitation for the components of mechanical trasmission unit and can causes a security problems and a loss of quality of service for passengers [6].

To create an anti skidding algorithms it is necessary to create an analitical charaterization of adhesion phenomena. It is important to make experimental observation on the trasmission force from the wheel to the rail [7]. A theorical studies of the skidding phenomena is difficult becauase there are the uncertain environmental conditions and the accidental causes [8]. It is difficult to make real experiments with real trains because it is not possible an exact observation of adhesion and skidding phenomena. So it is necessary to use software simulators of real trains. This kind of approach enalbles researches to make many different experiments in many different simulated conditions.

This paper presents the HiSpFuCo (High Speed Fuzzy Controller) as new model of control system for reducing problems and for improving high quality of service in high speed trains. This new model of control system is based on a fuzzy logic approach. The main goal of the HiSpFuCo is to reduce skidding phenomena in high-speed trains and to maximaze the adhesion between the wheel and the track.

This new model of control system differs from the others because the fuzzy logic approach is capable of making inferences even under uncertainty and then it is well suited for the adhesion and the skidding phenomena whiches are related with the uncertain environmental conditions and the accidental causes.

The experimental observation of physical phenomena related with the high-speed trains has been made with a simulator of an ETR500 which is also been used for the experiments for the HiSpFuCo.

Using a software simulator of a real train enables us to make a wide training set and a validation set for a learning approach in a neuro fuzzy network.

Fig. 1 The FS ETR 500

Fig.2 The FS ETR 500 cabin

2 Research platform

A simulator of the italian high speed train ETR 500 (Figures 1 and 2) has been used in a personal computer with a Pentium IV processor. A file , called expe.dat, with a full training set has been created at the end of 4500 different experiments. This simulator has been adapted for reading this file and for changing the weights of the neuro fuzzy network during the learning interval. One part of the experiments has been used for the training set and the other part for the validation set. Inputs data of the fuzzy logic controller are the slip speed in m/s and the pressure between the wheel and the rail. The output is the magnitude of the friction force.

3 Model of the traction drive system

In this context, the mathematical model of the traction drive system is based on the approach of each axle to be driven. The total weight of the train is considered distributed on the center of the axle.

3.1 Nomenclature

μ_d = friction coefficient
ω_r = angular speed of driving wheel
d = wheel diameter
F_a = friction force
R = resistance force
J = inertia of the rotating masses
m = translating masses
Q = normal force
T_{el} = electromagnetic torque
v = linear velocity
σ = slip referred to the driving wheel

3.2 Mathematical model

The mathematical model is created in the hypothesis that the angular velocity of each axle is ω_r . The model representing is given by the equations:

$$\begin{cases} (dv / dt) = F_a - R \\ d\omega_r / dt) = T_{el} - (d/2) F_a \end{cases} \quad (1)$$

starting from the translation and rotation equilibrium condition. The system is well represented in fig. 3.

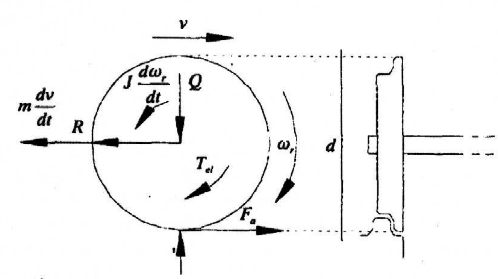

FIG. 3 Driven wheel representation

The slip can be expressed in this way:

$$\sigma = v - (d/2)\, \omega_r \quad (2)$$

The contact between the wheel and the rail is assumed to be in a single point.
A full adhesion will be only under this followed condition:

$$F_a \leq \mu d\ Q \quad (3)$$

3 Neuro-Fuzzy Controller for friction force

The main goal of several researches in the field of high speed railway is to know the maximum traction force that guarantees adhesion condition. For this reason it is relevant a determination of the friction coefficient μ_d dynamically and then a determination of the friction force according to the (3).

This paper presents the HiSpFuCo (High Speed Fuzzy Controller) as new model of control system for friction force of high speed train as represented in fig.4.

This controller consists of an MLP (Multi - Layers Perceptron) Network with six layers, that emulates a fuzzy system with 2 inputs, 6 membership fuctions, 9 fuzzy rules and one output.

The first layer of this network is for the two inputs, X1 and X2 of the fuzzy logic controller. X1 represents the train speed and X2 represents the slip speed. In this context for slip speed we consider the difference between the line speed of the wheel and the speed of the train. The second layer represents two section FUZ1 and FUZ2. They will calcolate the membership fuctions of the next layer: M_{11}, M_{12}, M_{13}, M_{21}, M_{22}, M_{23} . The 4th consists of nine neurons whiches represent the nine fuzzy rules

$$\begin{cases} R_1 = M_{11}\, M_{21}\ ; \\ R_2 = M_{11}\, M_{22}; \\ R_3 = M_{11}\, M_{22}; \\ R_4 = M_{12}\, M_{21}; \\ R_5 = M_{12}\, M_{22}; \\ R_6 = M_{12}\, M_{23}; \\ R_7 = M_{13}\, M_{21}; \\ R_8 = M_{13}\, M_{22}; \\ R_9 = M_{13}\, M_{23}. \end{cases} \quad (4)$$

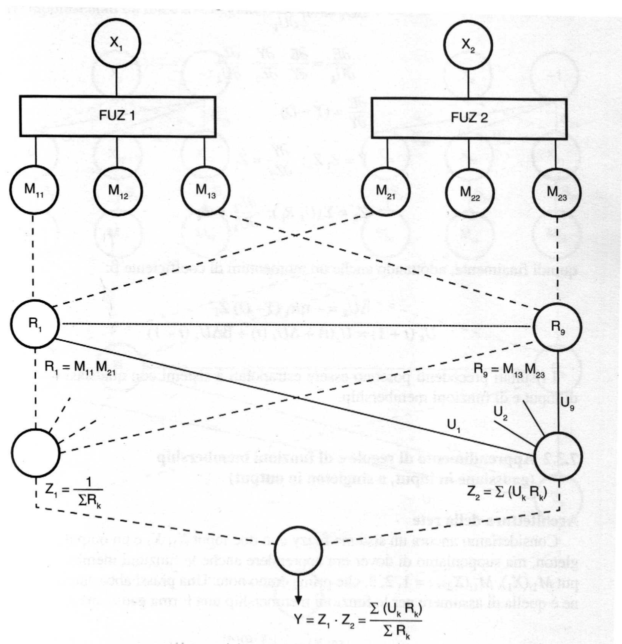

Fig. 3 The HiSpFuCo Neuro-fuzzy network.

The 5th layer represent two neurons Z_1 and Z_2:

$$\mathbf{Z_1 = 1/\,(\,\Sigma\, R_k\,)} \quad (5)$$

$$\mathbf{Z_2 = \Sigma\,(U_k\, R_k)} \quad (6)$$

The last layer represent the output of the fuzzy logic controller:

$$\mathbf{\mu_d = Y = Z_1\ Z_2 = \Sigma\,(U_k\, R_k)\,/\,(\,\Sigma\, R_k\,)} \quad (7)$$

The output of this network emulates the output of the fuzzy logic controller and it represents the friction coefficient μ_d.
In this context the membership function and the fuzzy rules are considered completely know before the learning.
The weights to be learned are Ui (i=1 to 9).
The HiSpFuCo uses the BP (Back Propagation) algorithm for learning. It considers the error

$$\mathbf{E = 1/2\ (Y - D)\ \hat{}2} \quad (8)$$

Y is the output of the network and D is the relative exact value in the training set.
The U_k weights will change as follow:

$$\mathbf{U_k\,(t + 1) = U_k(t) + \Delta\, U_k(t) + \beta\,\Delta\, U_k\,(t - 1)} \quad (9)$$

$$\mathbf{\Delta\, U_k = -\eta\, R_k\,(Y - D)\, Z_1} \quad (10)$$

The learning rate η and momentum β are controlled by a fuzzy logic system during the learning of the back propagation algorithm. This fuzzy system is composed of two inputs and one output. The inputs are **E** and **Δ E** the output is **Δ η. Δ β** is proportional to **Δ η.** The fuzzy rules are represented on the table 1.

E \ Δ E	Low	Medium	High
Low	P	P	ZE
Medium	P	P	ZE
High	ZE	ZE	N

Table. 1 Fuzzy rules; P = Positive; N = Negative; Ze= Zero.
The membership functions are three for each variable: two trapeziums and one triangle.

4 Simulations

The anti-skid neuro fuzzy system is applied to a simulation model of the high speed train ETR500. The model was previously validated at different speeds from Italian Railways.

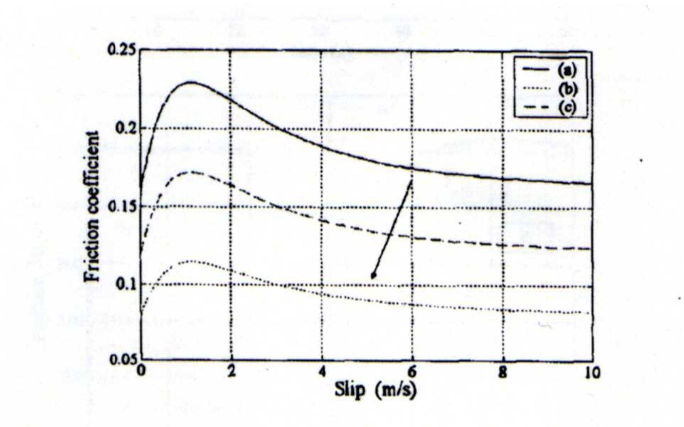

Fig. 4 Friction coefficient according to rail condition

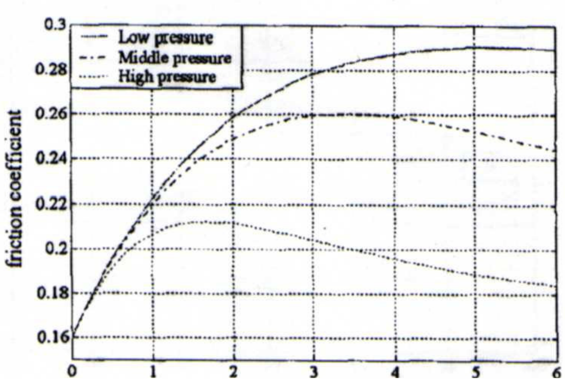

Fig. 5 Friction coefficient according to pressure

In figures 4 and 5 it is possible to see different friction coefficient with different slip velocity.
We used data of previous and real experiments with the real ETR 500 for creating our simulator.

4 Conclusions

The neuro-fuzzy logic approach permits to control the friction force after a period of learning also under uncertain situations.
Results demonstrate that we reduce the skidding phenomena with a determination of a friction force for the best adhesion between the wheel and the truck.
They have been obtained with a simulator of the italian train FS ETR 500. The nuero-fuzzy control system can be adapted in other kind of high speed train.

References:

[1] R. Rizzo and D. Iannuzzi, Indirect friction force identification for application in traction electric drives, *Proceeding of IFDICON,* 2001, pp. 33-40.
[2] Y. Onoda , T. Hirotsu , A. Tsuboi, Adhesion characterics and self-excited vibrations of driving axle system of individual drive rectifier A.C. locomotives. *Bullettin of JSME*, Vol. 8, No. 32,1965 pp. 584-592.
[3] T. Ramalingam, Amélioration de l'adhérence des locomotives électriques à courant continu. *Rail International*, 1988, pp. 41-48.
[4]M. Buscher, R. Pfeiffer , H. J. Schwartz, Raschlupfregelung für Drehstromlokomotives. *Elektrische Bahnen*, 1993, pp.163-178.
[5] R. Schreiber, R. Kögel, P. Häse, P. Hildenbrand, Regelung zur optimalen Kraftschlu ausnutzung bei behstromlokomotiven auf der Basis der Steigung der Kraftschlu kennlinien. *Elektrische Bahnen*, Vol. 93, 1995, pp.157-163.
[6] *Proceedings of World Congress on Railway Research*, Firenze 1997 e Tokio 1999.
[7] A.Balestrino, F.Bassi, O.Bruno, A.Landi, Modelling and multi axle wheelspin control of an electric locomotive, *Symposium on Power Electronics, Industrial Drives, Power Quality, Traction Systems Proceedings*, 1996, pp.C3:13-18.
[8] T. Hirotsu, Adhesion and dynamic phenomena during slipping of electrical rolling stock (1st Report), *Bullettin of JSME*, Vol. 12, 1969, pp. 511-521.