A microprocessor implementation of a stochastic anti-skidding device oriented to electrical traction drives

R. Di Stefano\textsuperscript{a}, S. Meo\textsuperscript{b} & M. Scarano
\textsuperscript{a}Dipartimento di Ing. Industriale, Università Cassino (Fr), Italy
\textsuperscript{b}Dipartimento di Ing. Elettrica, Università ‘Federico II’, Napoli, Italy

Abstract

The paper deals with a sequence of test and check procedures applied to an original prototype device, oriented to solve the anti-skidding problems on vehicles equipped with electrical drives. The proposed controller device is implemented on microprocessor board (INTEL\textsuperscript{®} 80960) and its performances are analysed in presence of different conditions. In particular the possibility to control in real time the dynamic performance of the drive in skid conditions by means of this hardware architecture is tested. The antiskid control algorithm, for these adopted tests, has been proposed by the Authors in previous notes \cite{1,2}. The aim of the control is the achievement of the maximum traction thrust in adherence condition. It bases itself on a stochastic evaluation of system parameters.

1 Introduction

In technical literature many anti-skidding systems have been proposed for traditional traction propulsor in order to control the braking and acceleration phases \cite{3,4,5}. These systems have the goal to reduce or to cancel the skid between wheel and road by means of the intervention on mechanical gears or hydro-pneumatic devices. The aim of the presented solution is to change directly the torque developed by the electrical traction machine in order to achieve the most suitable adherence conditions between wheels and road. This solution has to provide different activities and opportunities. First of all, in fact, it is necessary to consider an high dynamic vector control of the electrical machine in order to assign the desired kinematics trajectory to the motor according to the output quantities of the antiskid control device. Furthermore, if the evolution of adherence conditions are very quickly and the recovery of the security must occur in short time, it is necessary to perform the anti skidding control algorithm on a microcontroller architecture characterised as a high-performances computing engine. For this reason the Intel 80960 architecture has been chosen for the device implementation. In general the analysed schema can be represented as shown in fig.1. The traction drive is a set of static converters, electrical machine (DC
or AC motor) and all the control system devices (vectorial controller, speed analyser, observer system for parameters estimation and so on). For the following aims this structure will be seen as a set of differential equations that, for the actual value of speed, allows the evaluation of the traction torque, starting from the reference torque.

The anti-skidding controller has the aim to substitute, when it is necessary, the reference torque, set by driver, by a suitable value that allows the optimum running operations are achieved. The proposed controller bases itself on the knowledge, in real time, of different kinematic parameters of the whole system, available on board. By means of these values the controller determines the type of intervention following the implemented strategy.

The originality of this implementation is represented by the stochastic approach and by adopted architecture.

After the analysis of the environment and of the stochastic observer of the mechanical system a control strategy will be proposed and microprocessor simulations and implementations will be presented in order to detect the main features of such a system.

![Fig. 1 - General schema of considered traction system](image)

### 2 System dynamics

A simplified vehicle model suitable for the control, can be obtained considering the following assumptions:

1) to suppose a one dimensional mathematical formulation for the system wheel-road;
2) to neglect all the dissipative terms;
3) to consider the dynamics of actuators and suspensions as uncertainties on the friction adhesion coefficient value.

In this way, the dynamics of the system wheel-road, in no-adherence conditions can be written as (see list of symbols):

\[
\begin{aligned}
\frac{d\omega}{dt} &= \left(\frac{1}{J}\right)[M - F(\lambda, \omega)r] \\
\frac{d\lambda}{dt} &= -\left[\frac{(1 - \lambda)r}{\omega J} + \frac{1}{\omega rm}\right]F(\lambda, \omega) + \frac{(1 - \lambda)}{\omega J}M
\end{aligned}
\]  

(1)
This is a system of two differential equations with $F(\lambda, \omega)$, $\omega$ and $\lambda$ quantity unknowns. $F(\lambda, \omega)$ represents the expression of the tangential force during skid condition. The system of equations (1) is dependent on the parameter $F$, therefore it is necessary to define the relationship $F(\lambda, \omega)$. It is well known, in fact, that the function $F$ has been subject of study and that it has not yet got a clear mathematical interpretation because this function is very dependent on different variables as the speed, the normal force between wheel and road, the energy produced during the skid, the derivative of the acceleration and so on. The random nature of the set of these different interactions suggests a stochastic model for the formalisation of the function $F$. Therefore for this function the following model has been supposed:

$$F(\lambda, \omega) = \mu(\lambda, \omega)^* G$$  \hspace{1cm} (2)

The function $\mu(\lambda, \omega)$, as already discussed in previous notes [1,2], will be evaluated in stochastic mode.

In this paper, this function will be estimated, in real time, by Extended Kalman observer, by the knowledge of kinematic parameters of the whole system only. This observer is introduced in the following section.

3 Formulation of Extended Kalman Filter for estimating the function $F(\lambda, \omega)$.

As it is well known the extended Kalman filter [6,7] is an observer suitable for non linear system.

In this paper this observer has to be used for the evaluation of the status and of the parameter $F$. There are different methods for the extension of the Kalman filter to non-linear systems [8,9]. However it is necessary the definition of a new concept of status, called extended status, for which also the parameters are considered. For the consideration of the extended status the system eq. (1) can be re- written as:

$$\begin{align*}
x_1 &= f_1(x, u) = \frac{u_1}{J} - \frac{r}{J} x_3 + W_1 \\
x_2 &= f_2(x, u) = \frac{(x_2 - 1)x_3}{J x_1} - \frac{x_3}{x_1 r m} - \frac{(x_2 - 1)u_1}{J x_1} + W_2 \\
x_3 &= f_3(x, u) = c_0 - c_1 x_2 + W_3 \\
y_1(t) &= x_1 + V_1 \\
y_2(t) &= x_2 + V_2
\end{align*}$$  \hspace{1cm} (3)

Where about the function $F$, it has been assumed the following hypothesis:
\[ \frac{\partial}{\partial t} F(x, t) = c_0 - c_1 x_2 \]  

The noise on the measurement \( V(t) = [V_1, V_2] \) and the errors inside the model \( W(t) = [W_1, W_2] \) are considered as stochastic processes [1,2]. The extended Kalman filter algorithm is summarised in [1,2]. As in technical literature proved this method has not a sure convergence and, in general, the final solution could not be the optimal one; therefore this method must be tested by means a computer simulation in advance. This simulation has been presented by the authors in previous papers [1,2].

4 Skid Controller

The macro-subsystems of the analysed system are sketched in fig.2.

![Fig. 2 - Macro-functions of electrical traction drive](image)

In this figure the box of the torque conditioner represents the function of selection between the driver expectations and the anti-skidding device reference torque. In fact the output value of torque of the anti skidding device cannot be considered the absolute value of reference if the expectations of the driver are opposite to this one. Therefore the conditioner is a magic table of consents or no-consents in order to adopt the torque signal, of the anti skidding device as reference value according to the operations status.

The strategy that in this note is adopted is a proportional/integral type and can be formalised as:

\[ M'(h + 1) = M_0 \left[ 1 - k_1 \lambda - k_2 \sum_{i}^{h} \frac{(M_i - F_i r)}{M_0} \right] \]  

The philosophy of this strategy is the maximisation of the torque in max adherence conditions and the decreasing of the slip.

This strategy, by considering the data given by means of the observer, has the aim to achieve the adherence condition as soon as possible by adapting the value of the traction torque (reference torque) according to the adherence conditions in order to avoid the system instability by means alternative jumps over the limit borders. This condition could be produced by a high value of
traction torque with respect to the limit value in adherence and a following intervention of the controller.

5 System hardware

The actual value of reference torque represents, in the feeding algorithm function, the input value together with the motor speed. These data are adopted for the on-line integration of machines differential equations suitable to evaluate, according to the control strategy, the actual value of the phase currents reference (an AC motor drive is considered). The currents matrix is compared with the measured one and the intervention on the current modulator are activated.

In particular in this note a directed field oriented control of induction motor is implemented on board [10].

The system composed by mechanical components, by the induction motor and by the power feeding (see fig.4) has been simulated on a computer. The interface to the antiskid-control is formed by signals that represents the imposed current for the induction motor, the actual one, the wheel speed and the vehicle speed.

![Fig. 4 Simulation activities linked for the test (a), and main boards (b) ](image)

The block diagram shown in fig. 4(b) displays the actual components employed during tests. The block marked as PC represents a 486-40 MHz personal computer and is connected to the control board, marked CB, by means interface boards with analogic and digital lines.

The CB block is composed by an INTEL evaluation board for the i960 microcontroller, and by peripherals necessary to realise the interface with the PC. The main features of evaluation board and microcontroller are reported in fig. 5 that shows in details all the components employed for the control.

The i960 is part of INTEL 960 microprocessor family designed especially for embedded applications, it can sustain an instruction execution rate of seven and one-half million instruction per second (MIPS) with a burst rate of 20 (MIPS), moreover it offers an on-chip floating point processing unit and an efficient interrupt handling capability. This features are very useful to handle complex algorithms and large amount of data keeping an high speed rate in the instruction execution.
An A/D interface has been built-up to allow the analogic signals to be acquired. This one is composed by a 12 bit A/D converter with 1 µs of conversion time, by a simultaneous four channels sample and hold system and by a sequencer machine which provides to handle the whole conversion operation on four analogic channels when the start conversion signal is asserted. This structure is intended to get a fast HW solution and to reduce the CPU time instruction overhead.

![Fig. 5 Architecture of microcontroller](image)

### 6 Experimental Results

Tab. I shows the parameters of the induction motor used in the experiment. The time of the experimental tests is 20 seconds, instead the time of only one loop of the control is 3 ms. The rotating elements have the inertia equal to 0.01 kgm² and the wheel has a radius equal to 0.25 m. The initial value of \( x \) is \( x(0) = [21 \text{ rad/s}, 0, 26 \text{ Nm}] \). In order to underline the accuracy of the control the simulation tests activity is developed by comparing the results with a standard P.I. regulator. Figs. 6, 7 show the speed of vehicle and wheel. Fig. 6, in particular, shows the behaviour of the mechanical system when a standard P.I. regulator is adopted.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>1.2 kW</td>
</tr>
<tr>
<td>Stator resistance</td>
<td>0.302 Ω</td>
</tr>
<tr>
<td>Stator self inductance</td>
<td>28.66 mH</td>
</tr>
<tr>
<td>Mutual inductance</td>
<td>27.109 mH</td>
</tr>
<tr>
<td>Rotor resistance</td>
<td>0.33 Ω *</td>
</tr>
<tr>
<td>Rotor self inductance</td>
<td>29.15 mH *</td>
</tr>
<tr>
<td>Number of pole</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig 7 shows instead the speed when the proposed control is adopted. The increasing of the speed is relevant (about 20 %) in this case and the slip is however controlled. Figs. 8, 9 show the torque of the induction motor for the
compared cases. The fig. 9 confirms that in the proposed strategy the achievement of the maximisation of the torque has been reached and that, for all the simulated cases, the microcontroller has been able to control the dynamic behaviour of the system.

![Fig. 6 vehicle and wheel speed for a adherence recovery by a standard P.I. regulator](image1)

![Fig. 7 vehicle and wheel speed by means of the considered controller](image2)

![Fig. 8 Torque developed during adherence recovery by a standard P.I. regulator](image3)

![Fig. 9 Torque developed by means of the considered controller](image4)

**7 Conclusions**

In this paper is presented an implementation on microprocessor board (INTEL® 80960) of an anti skidding controller, based on the application of the extended Kalman observer. Its performances are analysed in presence of different experimental conditions and the results are discussed. This results are very good and confirm the possibility to control, in real time with a stochastic microprocessor control system the adherence conditions of a system wheel - road. Therefore, in the future, these types of controller will be widespread for the high quality traction drives in terms of security, safety and steerability of electrical vehicles.

**LIST OF SYMBOLS**

\( m \) mass of vehicle
railway operations

\( r \) wheel radius

\( t \) time

\( v \) translation speed of vehicle

\( G \) vertical force on the traction wheel

\( J \) inertia of rolling systems

\( \omega \) angular speed of traction wheel

\( M^* \) Reference torque

\( M = u_1 \) Traction torque

\[ \lambda = \frac{\omega - v}{w} \] with \( w = \max(\omega, \frac{v}{r}) \)

\[ [x_1, x_2, x_3] = [\omega, \lambda, F(\omega, \lambda)] \]

REFERENCES

1. Marino, P; Meo, S; Scarano, M: "Different strategies for antiskidding active control", Active Control in Mechanical Engineering, June 15-16-17 1993, Lyon - France.

2. Marino, P; Meo, S; Scarano, M: "A stochastic controller for anti skidding microprocessor system" 5th EPE'93, September 1993, Brighton U.K.


