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Combustion Engine air path: Fault-accommodation with sliding mode control framework

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Abstract— **This paper investigates second order sliding mode control. The use of the super twisting algorithm for the combustion engine air path is to achieve fault-tolerance and to enhance the chattering phenomenon. Comparing to the adaptive sliding mode controller (ASMC), the obtained results showed good performances for actuator fault-accommodation even in the presence of uncertainties on model parameters.** **Keywords: Nonlinear control, Fault-Tolerant Control (FTC), Sliding Mode Control (SMC), Super-Twisting Algorithm (STA), Combustion Engine air path.**

I. INTRODUCTION

The main motivations to develop combustion engine control algorithms are the reduction of exhaust gas to meet the requirements of emission standards EURO V and VI. These requirements could be fulfilled by using new and sophisticated control algorithms in order to provide the required engine torque which leads to a compromise between the optimal fuel consumption and a given exhaust gas emission level. The most harmful exhaust gas is the Nitrous Oxide (NOx). These NOx emissions and the phenomenon of engine smoke constitute a particular concern for modern combustion engines. In modern combustion engine, the automakers work in hardware devices such as Exhaust Gas Recirculation (EGR) and Variable Geometry Turbocharger (VGT) valves to control the NOx emissions. Primarily these emissions can be characterized by two feedback variables, namely the EGR rate and the Air Fuel Ratio (AFR) in the intake manifold. Since EGR and AFR fractions depend, in a complicated way, on the position of the EGR and VGT valves actuators, a coordinated control of the two actuators is necessary to meet emission level legislation. Earlier controllers implemented in Electronic Control Unit (ECU) use PID controllers in a closed-loop scheme. The purpose is to meet the AFR and the EGR fraction rate set-points computed from the static engine data provided by the manufacturer. However the tuning of these PIDs is very time-consuming and must be calibrated for every engine operating point using lookup tables. To overcome these difficulties, the attention of researchers has been focused on nonlinear control methods which do not need a calibration step. As in the literature, control design methods for the combustion engine air path have been proposed: Lyapunov control design [1], model-based control [2] [3], indirect passivation [4], dynamic feedback linearization [5][6], predictive control [7]. Most of these algorithms are control oriented models i.e. the control laws computed by these algorithms are based upon a model of the combustion engine air path. These controllers work badly because of discrepancies between the description model and the real system due to natural model parametric uncertainties or when faults occur in the engine. Modeling uncertainties arise from sources such as temperature change, external or internal disturbances. Engine faults occur in the combustion engine air path components. For example, an EGR or VGT leakage is a fault that affects the performance of any designed controller based on the methods previously quoted. Large variations in temperature ranges cause parametric variation during operation, affecting the uncertainties in the air path model and the actuator parameters, and can result in faulty performance of the controller [8]. This is the reason why robust nonlinear control methods are suitable in order to enhance the robustness of the controller making it less sensitive to parametric uncertainties and fault- tolerance. Fault Tolerant Control aims at guaranteeing stability and performance under system components faults. The main task to be tackled in achieving fault-tolerance is the design of a controller with a suitable structure to guarantee stability and satisfactory performance [9]. In [11], the emerging challenge is to accommodate the controller so that there can be a guarantee that the closed-loop system has admissible behavior in relation to an expected repertoire of faults. In [9], typically the required goal may be achieved through control robustness, system redundancy and reconfiguration or through fault compensation/accommodation. Fault-accommodation can be achieved in active or passive approach [10], [28], [29]. In order to overcome the difficulties met in conventional mapping/calibration based approaches in combustion engine control and ensure fault tolerance, Sliding-Mode Control (SMC) which is known to perform well under parametric uncertainties and external disturbances [12],[21], can be used to achieve fault-tolerance. In [13], [14] a multivariable control design for intake flow regulation of a diesel engine using sliding mode control was developed. Multivariable sliding mode controllers with integral actions in sliding surfaces to control outputs for different combustion modes were also proposed in [15]. The main disadvantage of classic sliding mode control consists in small oscillations at the output of the system whose effects can be harmful to motion control systems. This phenomenon well known under the name of chattering can appear due to fast dynamics which have been omitted from the model, fast switching discontinuous control and digital implementation issues. To overcome these difficulties, an extension to the high order sliding mode is necessary. Thus, in [16] the Higher-Order Sliding-

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Mode control (HOSMC) was used in order to reduce or to eliminate the chattering phenomenon at high frequencies. Several algorithms to carry out HOSMC have been developed in the literature (see [18] for a complete review). Among them, the Super-Twisting control algorithms (STA) require that the sliding variable be relative degree 1 with no need of the derivative of the sliding surface S. With its simplicity of implementation and its power to eliminate the chattering phenomenon, STA algorithms are preferable over the classic sliding mode [16], [17], [18],[26],[27]. This paper focus on fault accommodation of a combustion engine air path using the super twisting algorithm and a comparison to an adaptive sliding mode controller (ASMC) developed in [30]. The rest of paper is arranged as follows. Section II introduces the combustion engine air path modeling. Section III presents the engine fault tolerant control. Simulation results are given in section IV. Section V summarizes conclusions and describes the future work.

II. COMBUSTION ENGINE AIR PATH

The schematic diagram of the combustion engine is shown in [25]. At the top of the diagram we can see the turbocharger and the compressor mounted on the same shaft. The turbine delivers power to the compressor by transferring. The energy from the exhaust gas to the intake manifold. Together, the mixture of air from the compressor and the exhaust gas from the EGR valve with the injected fuel burns and produces the torque on the crank shaft. The presented combustion engine model was outlined in [1], [5] and recently validated experimentally in [19]. In order to obtain a simple control law, and due to the fact that the oxygen mass fraction variables are difficult to measure, the seventh-order model is reduced to a third-order one.

$$\begin{cases} \dot{p}_1 = k_1(W_c + W_{egr} - k_e p_1) \\ \dot{p}_2 = k_2(k_e p_1 - W_{egr} - W_t + W_f) \\ \dot{P}_c = \dfrac{1}{\tau}(\eta_m P_t - P_c) \end{cases} \tag{1}$$

where the compressor and the turbine mass flow rate (W_c and W_t) are related to the compressor and the turbine power (P_c and P_t) as follows:

$$W_c = P_c \frac{k_c}{p_1^{\mu} - 1} \tag{2}$$

and:

$$P_t = k_t(1 - p_2^{-\mu})W_t \tag{3}$$

Where: $k_c = \frac{\eta_c}{c_p T_a}$, $k_t = c_p \eta_t T_2$, $k_1 = \frac{R_a T_1}{V_1}$, $k_e = \frac{\eta_v N V_d}{R_a T_1}$ $k_2 = \frac{R_a T_2}{V_2}$

Notice that the real inputs are the EGR and the VGT actuator openings. The considered inputs, in this case for the sake of simplicity, are $u_1 = W_{egr}$ and $u_2 = W_t$, which are respectively the air flow through the EGR and the VGT actuators. So system (1) becomes:

$$\begin{cases} \dot{p}_1 = k_1(W_c + W_{egr} - k_e p_1) \\ \dot{p}_2 = k_2(k_e p_1 + W_f - W_{egr} - W_t) \\ \dot{P}_c = \dfrac{1}{\tau}(\eta_m P_t - P_c) \end{cases} \tag{4}$$

When replacing W_c and P_t by their expressions in (2) and (3), the simplified model can be expressed under the following control-affine form:

$$\dot{x} = f(x) + g_1(x)u_1 + g_2(x)u_2 \tag{5}$$

where $x = (p_1, p_2, P_c)^T$ and

$$f(x) = \begin{bmatrix} k_1 k_c \frac{P_c}{p_1^{\mu} - 1} - k_1 k_e p_1 \\ k_2(k_e p_1 + W_f) \\ \frac{-P_c}{\tau} \end{bmatrix} \tag{6}$$

$$g_1(x) = \begin{bmatrix} k_1 \\ -k_2 \\ 0 \end{bmatrix} \quad g_2(x) = \begin{bmatrix} 0 \\ -k_2 \\ K_o(1 - p_2^{-\mu}) \end{bmatrix} \tag{7}$$

with $K_o = \frac{\eta_m}{\tau} k_t$

We notice that the TDE model parameters $(k_1, k_2, k_c, k_e, k_t, \tau, \eta_m)$ have been identified under steady state conditions (i.e constant engine speed and constant fueling rate) and extensive mapping. To detail the description of the TDE model, the nomenclature of the TDE parameters can be found in [25].

In this paper, the proposal air path control strategy operates under the diesel conventional combustion mode conditions. This particular mode was characterized in [15]. In this work the authors suggested that for an optimal control performance, compressor mass flow W_c and exhaust pressure manifold p_2 are suitable choice for key output variable to be controlled. By a suitable change of coordinates, the authors in [25] proposed to replace the compressor mass flow set-point (W_{cd}) into an intake manifold pressure set-point (p_1). This transformation simplifies the control structure by defining new vector set-point (p_{1d},p_{2d}). The goal is now to find closed-loop controls which tracks these two new variables.

III. FAULT-TOLERANT CONTROLLER DESIGN FOR COMBUSTION AIR PATH

A. Super Twisting Algorithm

1) Background: Consider the nonlinear SISO uncertain system:

$$\begin{cases} \dot{x} = f(x) + g(x)u \\ S = s(t, x) \end{cases} \tag{8}$$

Where $x \in R^n$ is a state vector and $u \in R$ represents the control input. $f(x) \in R^n$ is a differentiable partially known vector field.

Assumption 1: A sliding variable $S = s(t, x) \in R$ is designed so that the system (8) desirable compensated dynamics are achieved in the sliding mode $S = s(t, x) = 0$.

Assumption 2: The system (8) input-output ($u \mapsto S$) dynamics are of a relative degree one, and the internal dynamics are stable.

Differentiating S with respect to time leads to:

$$\begin{aligned}\dot{S} &= \frac{\partial s(t,x)}{\partial t} + \frac{\partial s(t,x)}{\partial x}\dot{x} \\ &= \frac{\partial s(t,x)}{\partial t} + \frac{\partial s(t,x)}{\partial x}f(x) + \frac{\partial s(t,x)}{\partial x}g(x)u\end{aligned} \tag{9}$$

Which leads to:

$$\dot{S} = \Psi(t,x) + \Gamma(t,x)u \tag{10}$$

with: $\Psi(t,x) = \frac{\partial s(t,x)}{\partial t} + \frac{\partial s(t,x)}{\partial x}f(x)$ and
$\Gamma(t,x) = \frac{\partial s(t,x)}{\partial x}g(x)$.
We consider $w = \Gamma(t,x)u \leftrightarrow u = \Gamma^{-1}(t,x)w$ So we can write $\dot{S} = \Psi(t,x) + w$ and then, the solution of the system (10) is understood in the sense of Filippov [29] suspect to the following assumptions on the functions: Functions $\Psi(t,x)$ and $\Gamma(t,x)$,being uncertain, must satisfy the following conditions:

$$\begin{cases}\Phi > 0, |\Psi(t,x)| < \Phi \\ \quad 0 < \Gamma_1 < \Gamma < \Gamma_2\end{cases} \tag{11}$$

2) Control structure: The control objective is to steer the sliding variable S and its derivative to zero in finite time in the presence of the bounded perturbation with the unknown boundary by means of continuous control.
As in [22],[23], the super twisting algorithm consists of two parts:

$$u = \nu - \beta|S(t,x)|^{\rho} sign(S(t,x)) \tag{12}$$

With:

$$\dot{\nu} = \begin{cases} -\alpha sign(S(t,x)) & if \quad |u| \leqslant U_m \\ -U_m & if \quad |u| > U_m\end{cases} \tag{13}$$

Where U_m is a real constant and the gains satisfying the following conditions:

$$\begin{cases}\alpha > \dfrac{\Phi}{\Gamma_1} \\ \beta^2 \geqslant \dfrac{4\Phi}{\Gamma_1^3}\dfrac{\Gamma_2(\alpha+\Phi)}{(\alpha-\Phi)} \\ 0 \leqslant \rho \leqslant \dfrac{1}{2}\end{cases} \tag{14}$$

Ensures the convergence of the sliding manifold to zero in finite time.

B. Modeling uncertainties and actuator faults

In this section we describe the type of modeling uncertainties and actuator faults considered in this paper:

1) Actuator faults: In this paper we assume that the actuator fault enters in the system as additive disturbance. The faulty model can be written as:

$$\dot{x} = f(x) + g(x)(u + \ F(t,x)) \tag{15}$$

Where $F(t,x)$ is bounded by unknown positive function D_{act},

$$||\ F(t,x)|| \leqslant D_{act} \tag{16}$$

2) Modeling uncertainties: Unmodeled dynamics, model parametric uncertainties are represented by an additive term Δf to f. Where Δf is bounded by unknown positive function D_{unc}.

$$||\ \Delta f \ || \leqslant D_{unc} \tag{17}$$

Combining modeling uncertainties and actuator faults types, system (13) is rewritten as follows:

$$\dot{x} = f(x) + \Delta f + g(x)(u + \ F(t,x)) \tag{18}$$

3) STA controller for the diesel air path: Based on the equations (12),(13),(14), we propose an STA controller for the combustion engine air path model. Let us define the two following sliding mode manifolds S_1 and S_2 as follows:

$$\begin{cases} S_1 = p_1 - p_{1d} \\ S_2 = p_2 - p_{2d}\end{cases} \tag{19}$$

The closed-loop of the faulty system is written as follows:

$$\begin{cases}\dot{S}_1 = k_1 k_c \dfrac{P_c}{p_1^{\mu} - 1} - k_1 k_e p_1 + k_1(u_1 + F_1(t)) - \dot{p}_{1d} \\ \dot{S}_2 = k_2(k_e p_1 + W_f) - k_2(u_1 + u_2 + F_2(t)) - \dot{p}_{2d}\end{cases} \tag{20}$$

System (23) is rewritten as follows:

$$\begin{cases}\dot{S}_1 = \Psi_1(t,x) + \Gamma_1(t,x)u_1 \\ \dot{S}_2 = \Psi_2(t,x) + \Gamma_2(t,x)U\end{cases} \tag{21}$$

Where:

$$\Psi_1(t,x) = k_1 k_c \frac{P_c}{p_1^{\mu} - 1} - k_1 k_e p_1 - \dot{p}_{1d} + k_1 F_1(t) \tag{22}$$

$$\Gamma_1(t,x) = k_1 \tag{23}$$

$$\Psi_2(t,x) = k_2(k_e p_1 + W_f) - \dot{p}_{2d} - k_2 F_2(t) \tag{24}$$

$$\Gamma_2(t,x) = k_2 \tag{25}$$

$$U = -(u_1 + u_2) \tag{26}$$

Obviously fault-tolerant control based on the super twisting (12),(13),can be developed for system (22). The proposed STA controller for system (23)takes the following form:

$$\begin{cases} u_1 = -K_1 \displaystyle\int_0^t sign(S_1(h)dh - K_2|S_1|^{0.5} sign(S_1) \\ U = -K_3 \displaystyle\int_0^t sign(S_2(h)dh - K_4|S_2|^{0.5} sign(S_2)\end{cases} \tag{27}$$

Which lead to:

$$\begin{cases} u_1 = -K_1 \displaystyle\int_0^t sign(S_1(h)dh - K_2|S_1|^{0.5} sign(S_1) \\ u_2 = -u_1 + K_3 \displaystyle\int_0^t sign(S_2(h)dh + K_4|S_2|^{0.5} sign(S_2)\end{cases} \tag{28}$$

In the next section, we state our main results.

4) Main result:

Theorem 1: Consider the uncertain faulty system (23). The fault accommodation STA controller (30) under gains conditions as in (43) ensure that the sliding manifolds $[S_1,S_2]$ converges to zero in finite time.

Proof: Let consider the closed-loop of the system in the faulty case. It can be rewritten in two subsystems:

$$\begin{cases} \dot{S}_1 = -k_1K_2|S_1|^{0.5}sign(S_1) + k_1\nu_1 + \Psi_1(t,x) \\ \dot{\nu}_1 = -K_1sign(S_1) \end{cases} \tag{29}$$

$$\begin{cases} \dot{S}_2 = -k_2K_4|S_1|^{0.5}sign(S_2) + k_2\nu_2 + \Psi_2(t,x) \\ \dot{\nu}_2 = -K_3sign(S_2) \end{cases} \tag{30}$$

Let us consider $\Psi_i(t,x) \leq \gamma_i \mid S_i \mid^{0.5}$.

For each subsystem (31)and (32), we propose the following candidate Lyapunov function

$$\begin{aligned} V_i = 2K_j \mid S_i \mid + \frac{1}{2}k_i^2\nu_i^2 + \\ \frac{1}{2}(k_iK_{j+1} \mid S_i \mid^{0.5} sign(S_i) - k_i\nu_i)^2 \end{aligned} \tag{31}$$

In the quadratic form, the proposed Lyapunov function can be written as:

$$V_i = \Theta_i^T P \Theta_i \tag{32}$$

Where $i = (1;2)$, $j = (1;3)$

$$\Theta_i^T = [|S_i|^{0.5}sign(S_i), \nu_i] \tag{33}$$

And

$$P_i = \begin{bmatrix} 2K_j + \frac{1}{2}(k_iK_{j+1})^2 & -\frac{1}{2}k_i^2K_{j+1} \\ -\frac{1}{2}k_i^2K_{j+1} & k_i^2 \end{bmatrix} \tag{34}$$

The novelty here is the fact that $k_i > 0$ (parameter of the engine model) changes the structure of the matrix P, in other words Γ_i is different to 1.

Note that V is continuous but not differentiable at $S_i = 0$. It is positive definite and radially unbounded if $K_j > 0$,i.e,

$$\lambda_{min}(P_i) \mid\mid \Theta_i \mid\mid_2^2 \leq V_i(t,\Theta_i) \leq \lambda_{max}(P_i) \mid\mid \Theta_i \mid\mid_2^2 \tag{35}$$

Where $\mid\mid \Theta_i \mid\mid_2^2 = \mid S_i \mid + \nu_i^2$ is the Euclidean norm of Θ_i. Its time derivative along the solutions of the subsystem (31) is:

$$\dot{V}_i = -\frac{1}{\mid S_i \mid^{0.5}}\Theta_i^T Q_i \Theta_i + \frac{\Psi_i(t,x)}{\mid S_i \mid^{0.5}} q_i^T \Theta_i \tag{36}$$

Where

$$Q_i = k_iK_{j+1} \begin{bmatrix} 2K_j + \frac{1}{2}(k_iK_{j+1})^2 & -\frac{1}{2}k_i^2K_{j+1} \\ -\frac{1}{2}k_i^2K_{j+1} & k_i^2 \end{bmatrix} \tag{37}$$

And

$$q_i^T = (2K_i + \frac{1}{2}k_i^2K_{j+1}^2 - 2k_iK_{j+1}) \tag{38}$$

Applying the bounds for the perturbations as given in [24], (38) could be reduced to:

$$\dot{V}_i \leq -\frac{k_iK_{j+1}}{2 \mid S_i \mid^{0.5}}\Theta_i^T \tilde{Q}_i \Theta_i \tag{39}$$

Where

$$\tilde{Q}_i = \begin{bmatrix} 2K_j + (k_iK_{j+1})^2 - (\frac{4K_j}{k_iK_{j+1}} + k_iK_{j+1})\gamma_i & \star \\ -k_i^2K_{j+1} + 2\gamma_i & k_i^2 \end{bmatrix} \tag{40}$$

In order to guarantee $\tilde{Q}_i > 0$,the controller gains must satisfy the following relations:

$$K_{j+1} > \frac{2\gamma_i}{k_i^2}, K_j > k_iK_{j+1}\frac{5\gamma_ik_iK_{j+1} + 4\gamma_i^2}{2(k_iK_{j+1} - 2\gamma_i)} \tag{41}$$

Then $\tilde{Q}_i > 0$ under the inequalies above, implying that the derivative of each Lyapunov function is negative definite. Therefore, the two sliding surfaces $[S_1, S_2]$ converge to zero in finite time where the convergence time is upperbounded by $T_c = \frac{2V_i(Si(0))^{0.5}}{\tilde{\gamma_i}}$ and $\tilde{\gamma_i} = \frac{\lambda_{min}^{0.5}(P_i)\lambda_{min}(\tilde{Q}_i)}{\lambda_{max}(P_i)}$.

C. Adaptive Sliding Mode Control law for the TDE air path

In order to compare the STA control performances, we use an adaptive sliding mode control (ASMC) law as proposed in [30] to reach active fault tolerance. With the same surfaces defined in the previous paragraph, the control laws are elaborated as follows:

$$\begin{cases} u_1 = -c_1(t).sign(S_1(t,x)) \\ u_2 = -u_1 + c_2(t).sign(S_2(t,x)) \end{cases} \tag{42}$$

With the adaptive gains $c_i(t)$ defined such that

$$\dot{c}_i(t) = \begin{cases} \overline{c_i}.|S_i|.sign(|S_i| - \varepsilon) & if \quad \overline{c_i} > \lambda \\ \lambda & if \quad \overline{c_i} \leqslant \lambda \end{cases} \tag{43}$$

A proof of this algorithm is developed in [30] with the way to choose the different constant parameters in it.

IV. Simulation results

The performances of the controllers (28) and (42) were evaluated in real time Software In the Loop (SIL) simulations using the Dspace modular simulator. The real-time platform is based on the DS 1006 board interfaced with Matlab/Simulink software designed for processing both the combustion engine real time reduced third order model developed in (1-5) and controllers STA. The engine used is a common rail direct-injection in-line 4-cylinder provided by a French manufacturer. Isentropic efficiencies of the turbine, the compressor and the mechanical turbocharger were determined from the maps provided by the manufacturer. The values of model parameters k_1, k_2, k_c, k_e, k_t, τ_o, η_m are taken as in [4]. To make it simple, additive model parametric uncertainties is used in the simulation:

$$P_n \subset P, P_n = P_{0n} + \delta p_{0n} \tag{44}$$

Where P_{0n} $(1 \leq n \leq 7)$ is the nominal value of the parameter P_n, $\delta p_{0n} \subset [0,1]$ is the uncertainty on this parameter in such way that 10 % uncertainties in the TDE model parameters means that the model parameter used in the control synthesization is (1-10%). At the same time, we keep the nominal model parameter values for the ASMC and the STA controllers. To avoid the chattering associated with the sliding motion for the ASMC, a well-known continuous approximation of the function sign(S) [21] is given by:

$$Sign(S) = \frac{s}{|s| + \xi} \tag{45}$$

Where ξ is a small positive constant. This approximation is used to ensure that the sliding motion will be in the vicinity of the line (S=0). The approximation of the sign function was implemented with $\xi = 0.01$.

A. STA and ASMC performances against modeling uncertainties

1) Case : Parametric uncertainties (10%): We evaluate the performances of the STA and ASMC controllers with parametric uncertainties on the combustion air path model. In order to track the trajectories set-points, we choose the constant gains of the ASMC as fommows:$\overline{c_i} = 2.5$ and $\lambda = 0.5$.

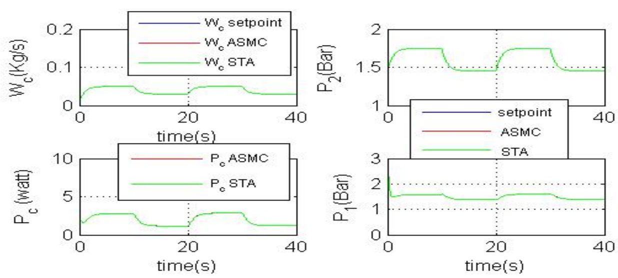

Fig. 1: Performances of STA and ASMC controllers with 10% parametric uncertainties

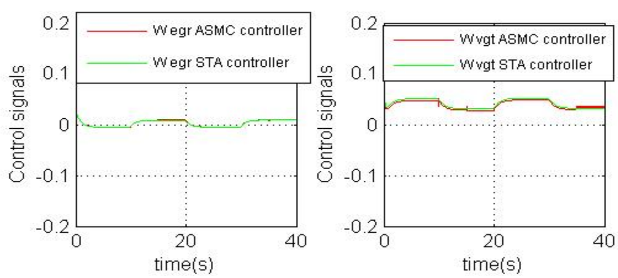

Fig. 2: Control signals of STA and ASMC with 10% parametric uncertainties

B. STA fault-tolerance against actuator faults

1) Case 1: STA and ASMC controllers against leakage: In Fig. 3. and Fig. 4., we can see that the STA controller performs well despite the occurrence of fault actuators. We observe good tracking trajectories even if the apparition of the faults (the EGR and the VGT leakage) has little effect in control signals of the ASMC. This shows the robustness of the STA controller face to modeling uncertainties and actuator faults.

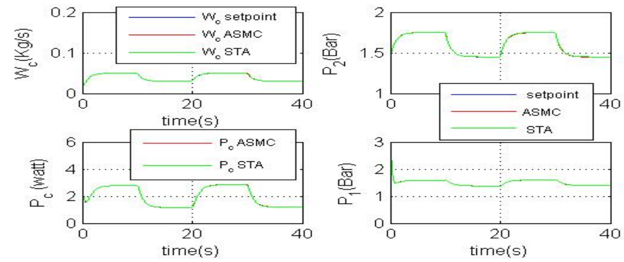

Fig. 3: Performances of the STA and ASMC controllers with actuatorleakage

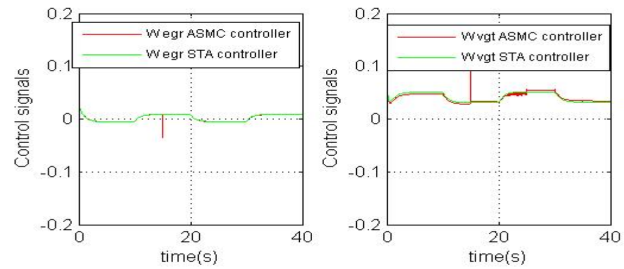

Fig. 4: Control signals

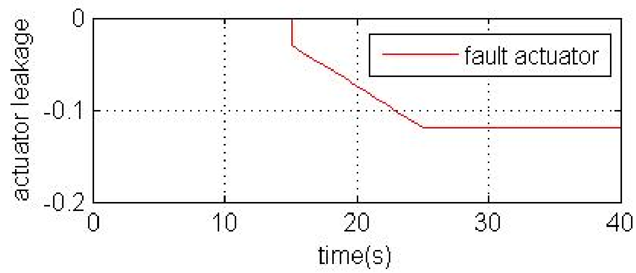

Fig. 5: Faut actuator form: leakage time varying

2) Case 2: leakage periodic time varying and comparison to the second ASMC in [30]: In order to show the good performances of the STA controller in fault-tolerance, we consider a fault type scenario modeled by time varying additive faults which occurs at t=15s as follows:

$$F(t,x) = \begin{cases} 0 & if \quad t < T \\ \theta_0 sin(2\pi f_0 t) & if \quad t \geq T \end{cases} \tag{46}$$

Where $\theta_0 = -0.1$ and $f_0 = 0.1$ Hz are respectively the amplitude and the frequency of the periodic signal.

In Fig.6., the results show good performance with the STA controller compared to the ASMC one. In this case, we get an actuator leakage periodic like a sinus function. A great reduction of the chattering phenomenon is clearly shown with the STA controller in Fig.7 and no effect of the leakage in the tracking trajectories. However, despite the good performances of ASMC controller to fault accommodation,we notice that the chattering phenomenon becomes important after the periodic actuator leakage occurrence. Its effects are seen in the evolution of p2 in Fig.6. and clearly in the evolution of the control signals in Fig.7.

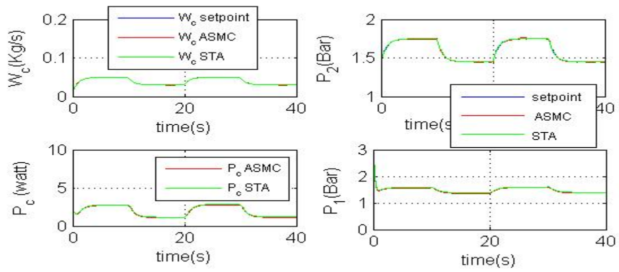

Fig. 6: Performances of fault-tolerance: comparison between STA and ASMC controllers with periodic time varying leakage at t=15s

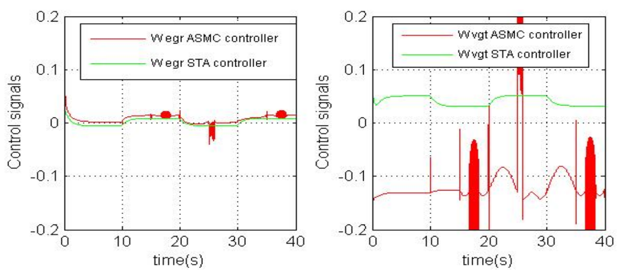

Fig. 7: Control signals perfomances of STA versus ASMC

V. CONCLUSION AND FUTURE WORKS

In this paper, STA and ASMC for controlling the combustion engine air path have been proposed. Simulation results show good performance for the two controllers in terms of tracking error, robustness, model parametric uncertainties and fault-tolerance. In addition, the Super-Twisting controller significantly reduces the chattering phenomenon induced by the classical sliding controller. In the near future, we plan to develop new active fault-tolerant control strategies based on adaptive gains STA with control actuator saturation.

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