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Influence of driving cycles on Euro 3 scooter emissions and fuel consumption

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ABSTRACT

Regulated pollutant emissions and fuel consumption were characterized at the exhaust of two Euro 3 4-stroke medium-size motorcycles during the execution of both standard and real world driving cycles. A principal component analysis was carried out to group in a cluster the driving cycles with similar kinematic parameters. Hot start results, analysed according to this cluster grouping, show that the main differences are explained by overall mean speed and high positive acceleration of driving cycles. Lower mean speeds produce higher CO_2 emission factors, while the influence on CO and HC is more complex. NO_X are not significantly affected by the driving pattern. Inside the same cluster, the whole duration of the acceleration phases could discriminate emission behaviour. In-depth analysis of cold start results was conducted in order to assess the influence of the driving cycle and vehicle characteristics on cold start duration. Cold start extra emissions are more influenced by the duration of the enrichment phase than by the catalyst light-off. The larger number of accelerations occurring during real world driving cycles produces higher variability of air fuel ratio and hence higher cold start extra emissions.

1. Introduction

Two-wheeler motorcycles are widely used for private transportation for short distances in urban areas, especially in Italy. In 2008, powered two-wheelers (PTWs) accounted for over 32 million vehicles in EU-27, representing about 8% of passenger mobility fleet [1]. This share showed a significant increase in Italy, where PTWs cover almost 20% of all on-road circulating vehicles. With over nine million two-wheelers, Italian fleet contributed for 28% to EU-27 figures [1]. Always with reference to the Italian situation, in 2009 PTWs fleet included 33.3% of mopeds (vehicles with an engine capacity lower than 50 cm^3), while motorcycles engine displacement classes accounted for 18% ($\leqslant$125 cm^3), 20.4% (126–250 cm^3), 21% (251–750 cm^3) and 7.4 (>750 cm^3), respectively [2,3].

Comparison between emissions produced by two-wheelers and passenger cars reveals that two-wheeler emissions are far from negligible, probably because the after treatment technologies for motorcycles are not as efficient as those for cars [4,5]. Together with the increasing number of circulating motorcycles, this makes it necessary to improve engine technology and exhaust gas treatment [6–8], taking into account that their contribution to air pollution is generally growing, especially in urban environment. In a study referred to the city of Genoa between 1992 and 2010 [9], motorcycles contributions to CO and HC total emissions were estimated to be around 38% and 27%, respectively, in 2010. Available strategies to control emissions already in use on passenger cars are often not used on motorcycles because they prove too expensive in relation to vehicle cost and their real effectiveness [10].

Moreover, two-wheeler vehicles are a major urban source of unregulated pollutants hazardous to environmental and human health. The poor combustion quality occurring in two-stroke motorcycle engines or in four-strokes not tuned in terms of air fuel ratio is often responsible for high unburned hydrocarbons and particle emission levels [11–13].

Two-wheeler emissions in urban areas mainly stem from driving conditions and the cold start phase which becomes a major factor in short distance travel [14,15]. Previous studies were carried out to investigate the driving factors influencing motorcycle emissions [16]. According to [17], the effect of urban compared with rural driving is visible on fuel consumption (approximately 30% more fuel), whereas emission differences between the two driving patterns are not statistically significant.

With regard to contribution of cold start, emissions of CO, HC and CO_2 in urban driving are considerable and even rise for lower ambient temperature levels. However, experimental measurements show that the after-treatment systems of Euro 3 motorcycles do reduce pollutant emissions in hot operation mode [18]. Moreover, incomplete combustion occurring during cold start causes high toxicity due to the presence of toxic VOCs [19]. Widely investigated three-way catalyst technology for 4-stroke motorbikes failed to reduce

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Nomenclature

CAN	canonical variable
CFV	Critical Flow Venturi
CO	carbon monoxide
CO_2	carbon dioxide
CVS	Constant Volume Sampling
DC	driving cycle
EFI	Electronic Fuel Injection
EUDC	extra-urban driving cycle
FDA	factorial discriminant analysis
GPS	global positioning system
HC	total hydrocarbons
IRC	inrets route court
IUFC	inrets urbain fluide court
NO_X	nitrogen oxides
PCA	principal component analysis
PEMS	portable emissions measurement systems
PTW	powered two-wheeler
SAI	secondary air injection
SM	Single Mode (of the driving cycle)
T_{acc}	time percentage in acceleration phase
T_{dec}	time percentage in deceleration phase
T_{cruise}	time percentage in cruise at constant speed
T_{idle}	time percentage at idle
UDC	urban driving cycle
VOCs	volatile organic compounds
WMTC	World Motorcycle Test Cycle
λ	relative air–fuel ratio

aromatic HC emissions at cold start which is 2–3 orders of magnitude higher than those of current passenger cars [20]. Taking into account the contribution of two-wheelers to road transport pollution and in order to verify some of the quoted results with reference to an European context, both for the selected vehicles and driving cycles, a wide investigation on motorcycles emissions is being jointly performed by Istituto Motori of National Research Council (IM-CNR) and the Internal Combustion Engines Group (ICEG) working at the University of Genoa. The main goals of the research activities are the analysis of the influence of the driving characteristics on exhaust emissions and fuel consumption, a deeper comprehension of the engine and after-treatment system behaviour within the cold start transient and the evaluation of cold start additional emissions for different two-wheelers classes. In a first step, the growing contribution of cold emissions to the total released quantities with the development of the legislation on exhaust emissions was highlighted: the share of cold start CO and HC additional emissions on urban trips was estimated around 25% for Euro 2 4-stroke catalysed motorcycles, increasing to 45% for Euro 3 vehicles of the same type [21]. It was also observed that information on the most recent Euro 3 class was poor, with particular reference to the assessment of real world and cold transient performance of the wide variety of vehicles belonging to this class. The presented experimental work aims therefore to determine the influence of driving cycles on the fuel consumption and emissions of two Euro 3 medium-size motorcycles (so-called scooters). They were tested on a chassis dynamometer during 14 real and legislative driving cycles for measuring emissions of carbon monoxide (CO), total hydrocarbons (HC), nitrogen oxides (NO_X) and carbon dioxide (CO_2). A wide statistical analysis was then developed in order to identify the most influencing kinematic parameters on fuel consumption and hot emissions. Finally, in-depth analysis of cold start transient was also conducted to assess the influence of vehicle technological characteristics and kinematic parameters of certain driving cycles on cold start duration, travelled length and extra-emission.

2. Experimental setup

2.1. Vehicles

The two scooters are 4-stroke in use scooters approved according to Euro 3 legislative stage (Table 1), differing in engine displacement, weight, fuel system injection and exhaust after-treatment. Scooter A is equipped with a three-way catalyst which works in stoichiometric condition thanks to a lambda sensor and an Electronic Fuel Injection system. Scooter B, instead, is equipped with an after-treatment catalyst which works in the presence of a non-controlled air/fuel ratio. In this case, the reduction in CO and HC over the catalyst is enhanced by the injection of secondary air (SAI) in the engine exhaust duct. The flow of secondary air is tuned by the backpressure at the engine exhaust. The after-treatment lay-out including SAI is commonly applied by OEMs to vehicles fitted with carburettor, which still cover a significant market share for Euro 3 two-wheelers with an engine displacement up to 150 cm^3 [2,3]. Both scooters failed to comply with European type approval legislative standards for exhaust emissions. Scooter A exceeded limits for all regulated pollutants (CO, HC and NO_X); scooter B exceeded the CO limit.

2.2. Experimental apparatus

The scooters were tested on a two-wheeler chassis dynamometer (AVL Zollner 20" – single roller) able to simulate vehicle inertia (from 80 to 450 kg) and road load resistance according to the procedures laid down in Directive 2003/77/EC. Before each test in cold start conditions, the scooter was kept at a relatively constant temperature between 20 °C and 25 °C for at least 8 h. A variable speed cooling blower was positioned in front of the scooter so as to direct the cooling air to the motorcycle in a manner simulating actual operating conditions. A driver's aid displays speed trace of the driving cycle to be followed with a tolerance of ±1 km/h. During the tests the exhaust gases were diluted with ambient purified air by a dilution tunnel connected to a Constant Volume Sampling with Critical Flow Venturi (AVL CFV-CVS) unit. Throughout the tests a continuous flow of diluted mixture filled one or more bags so that concentrations (average test values) of carbon monoxide, unburned hydrocarbons, nitrogen oxides and carbon dioxide were determined in succession. Tailpipe average test values and continuous diluted emissions (with 1 Hz resolution) were measured by an exhaust gas analysis system (AVL AMA 4000). Moreover, fuel consumption was computed by using the carbon balance method as described in Directive 93/116/EC. During some tests, a portable emissions measurement systems (PEMS), SEMTECH by Sensors, was connected to the scooter exhaust to measure the key engine-out gaseous emissions. A series of thermocouples were used to measure temperatures upstream and downstream of the catalyst. Fig. 1 shows the experimental set-up.

2.3. Driving cycle characteristics

Emissions were measured over the following driving cycles (DC):