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*Focussed on: Fracture and Structural Integrity related Issues*

# Field Load Acquisition and variable amplitude fatigue testing on maxi-scooter motorcycles

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**ABSTRACT.** Aim of the present work was the instrumentation of a maxi scooter for the field collection of service loads acting on the scooter main components such as frame, fork, handlebar, rear frame and suspension. Service loads were collected on an instrumented Yamaha Tmax scooter equipped with 22 channels during a set of field tests that were representing a predefined road mix, covering a mileage of 270 km. Field load histories were used to develop an accelerated test procedure for the accelerated bench fatigue testing of a new model prototype whose mission was set to 50000 km. The acceleration procedure allowed a time reduction from 1600 hrs to 122 hrs bench equivalent testing. Both the benchmark scooter Tmax and a maxi-scooter prototype under development underwent the bench variable amplitude fatigue testing. The results of the fatigue tests on the prototype allowed to identify some critical bolted connections and to reduce some stress concentration features causing the appearance of small cracks that were found also after during 50000 km of driving tests.

**KEYWORDS.** Motorcycle; Field data collection; Accelerated variable amplitude fatigue; Cracked components.

## INTRODUCTION

The development of a new motorcycle model is a long and complex process that involves several fields of knowledge ranging from the styling, the design of frame-suspensions-engine components, the virtual assessment of components, the prototyping, the bench testing and the final driving tests: in that process, manufacturers can rely on their former experience and on the support of component manufacturers, depending on their industrial size and historic production.

Usually, experiences from a small vehicle are useful but not enough to develop a more powerful vehicle: on the other side, also strong experiences in the automotive or motorcycle market may not be enough to enter in a new market as, for instance, the maxi-scooter market that is nowadays bridging between the small city scooter vehicles and the road motorcycle family.

Over the last decades, a lot of investigation was carried out by manufacturers and researchers in order to establish a proper set of methodologies supporting the development of motorcycles, nowadays usually implemented in the industry. The first set of information needed by engineers regarded the loads acting on the components of scooter or motorcycles: this was approached by the application of sensors to the component of the vehicle [1-4] or in some cases by the development of customized load cells to be applied to the vehicle components for the complete measurement of loads acting on the vehicle interfaces with the ground [5,6] or with the rider [7]. On the basis of this set of information, engineers can develop methods for the virtual assessment of main components of the motorcycle such as frames and suspensions [7-9] by using multibody codes for the prediction of vehicle dynamics or finite element analysis for the assessment of frame stiffness properties and fatigue life of casted, CNC machined and welded components.

The use of laboratory tests has always been supported by manufacturers as a tool for ensuring experimentally the durability of their product, despite the lack of mandatory regulation from an international body. Manufacturers are responsible for any damage that customers can encounter during the supposed use of their vehicle, therefore they have to ensure the degree of safety of the product under their responsibility. Laboratory tests however, as we can find in the manufacturers or research centers laboratory, can range from simple single channel constant amplitude fatigue tests [8,10], to multiple channels variable amplitude fatigue tests [11-15] of the full vehicle [11,15] or of its components [12,13]. Within the different experiences developed throughout the world, further distinction can be made between the benches involving a dummy in the tests, therefore using inertial forces to reproduce the actions stressing the vehicle [3,11], and the benches involving a reaction frame around the component [10,12,13,14].

Variable amplitude testing of full motorcycles, despite its appealing ability of reproducing exactly the load histories measured in the field, require acceleration procedures to ensure that the mileage demanded from the component assessment may be reproduced in a reasonable and industrially sustainable amount of time. Very few information are available in the literature regarding these acceleration procedures [14,15] as this may be the bottleneck of the procedure or the real know-how that companies tend to protect.

Aim of the present work was the instrumentation of a maxi scooter for the field collection of service loads acting on the scooter's main components such as frame, fork, handlebar, rear frame and suspension. Service loads collected during a representative amount of field tests were used to develop an accelerated test procedure for the accelerated bench fatigue testing of a new model prototype comparison.

## OVERALL METHOD DESCRIPTION

The method adopted for the study was defined starting from the request of a motorcycle manufacturer for the fatigue assessment of a new prototype of maxi-scooter that was under development (prototype P1), whose final version was not yet equipped for road tests. The manufacturer wanted to make sure that the prototype P1, supposed to be used for the early design stage road tests, would ensure to test drivers the proper fatigue durability and survive a 50'000 km drive test campaign without any failure on main safety components. The study then was based on a service loads collection campaign using an existing maxi-scooter produced by a competitor, chosen by the prototype manufacturer as similar in dimensions and performances. The scooter was a Yamaha Tmax, 500 cc: two samples of this motorcycle were available for the study. The first sample, named TmaxS was instrumented and calibrated for the field data collection.

The instrumented scooter TmaxS was also used to tune the fatigue test bench and to verify the amount of fatigue damage that was applied by the accelerated test load histories on the bench with respect to the target fatigue damage as collected from the field tests. The second sample, named TmaxD, was used for the fatigue testing of the commercial scooter. The prototype sample P1 underwent the same fatigue tests of the TmaxD to verify its ability to survive to the assumed target life.

## VEHICLE INSTRUMENTATION

The maxi-scooter TmaxS was prepared for the application of a large number of channels, in order to have a certain degree of redundancy in the evaluation of loads and solicitations acting on the scooter.

The full list of applied channels, their name and units, the type of sensor used are listed in Tab. 1. The location and sign convention of most of them are presented in Fig. 1. As it can be appreciated, most of the channels were strain gauge channels directly applied to the motorcycle components: as a measuring principle, the intrinsic compliance of the component under single load components was used to obtain a channel calibrated in the assembled configuration of the scooter.

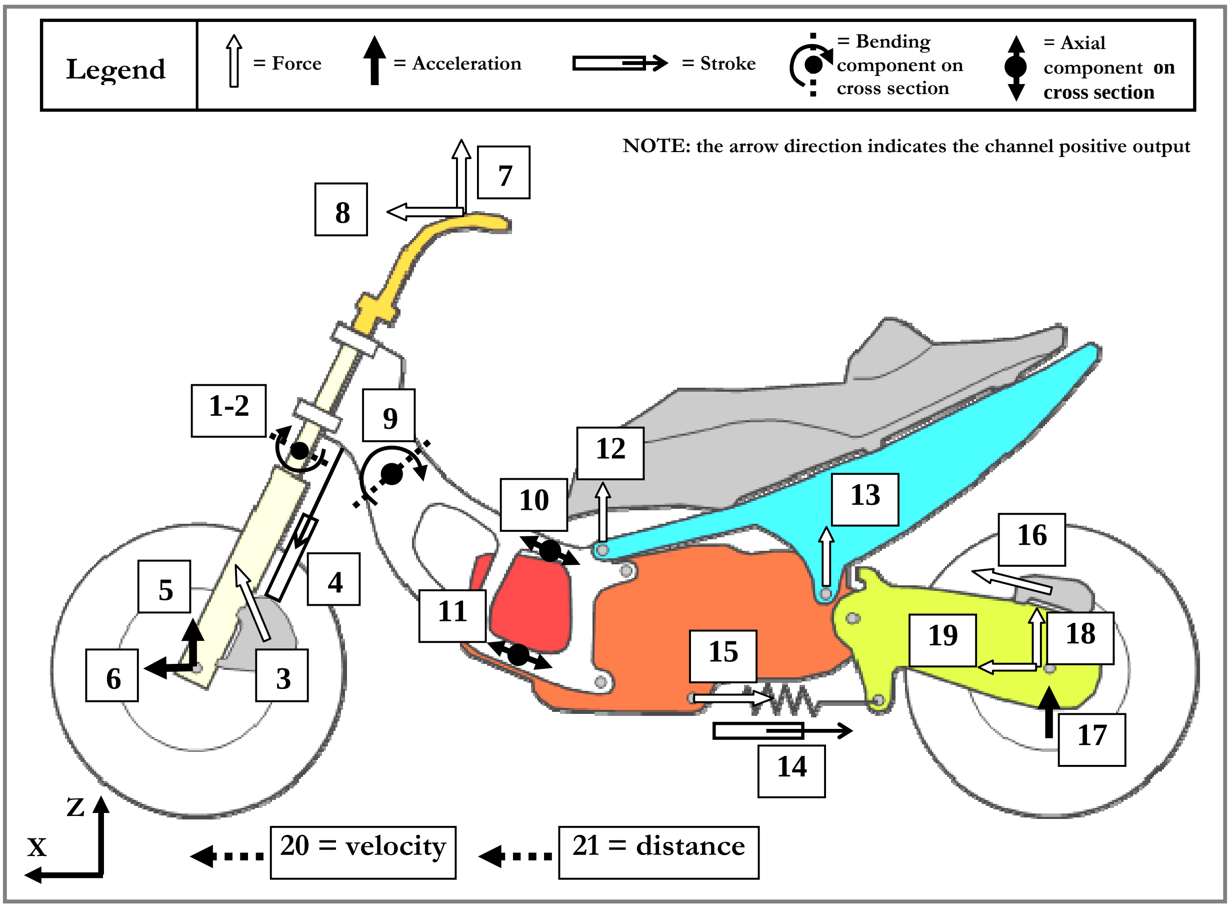


Figure 1: Location and sign convention of channels applied to scooter Yamaha TmaxS.

Signal obtained from the field were therefore converted into mechanical loads on the basis of a calibration procedure aiming to apply known single load components to the assembled vehicle. Only few channels were based on load cells intentionally designed for the quantity under measurement: this was the case of the rear damper force as well as the front and the rear brakes. In fact, in the case of the rear damper, the solid shaft at the damper extremity was notched by a trough hole in order to create a bending component to be sensed by means of half brigde (longitudinal & transverse grids, Fig. 2.c).

Regarding the front and rear brake calipers, the arms connecting the caliper to the fork or the swing arm were slimmed in such a way that the tangential force acting on the calipers was creating a cantilever action on the arms, therefore making the full bridge unbalanced under the effect of the braking load.

## VEHICLE CALIBRATION

Calibration constants of single component strain gauge bridges were obtained as inverse values of channel Sensitivity, intended as the linear regression slope between the electrical output [mV] of the channel and the known applied forces [N] or bending moment [Nm]. In the case of coupling between the channels, as in the case of the handlebar or the rear wheel axle, a matrix approach was adopted.

Calibration tests were performed on the fully equipped scooter, ready to ride. This allowed to avoid the effect of reassembling the component after calibration, but introduced the complexity regarding the alignment of loads and the restraining of the vehicle. Calibration loads were applied by deadweights and pulleys or by means of hydraulic actuators. Only exception was the rear damper, calibrated by means of a tensile machine as it was working in tension (see the sketch in Fig. 1).

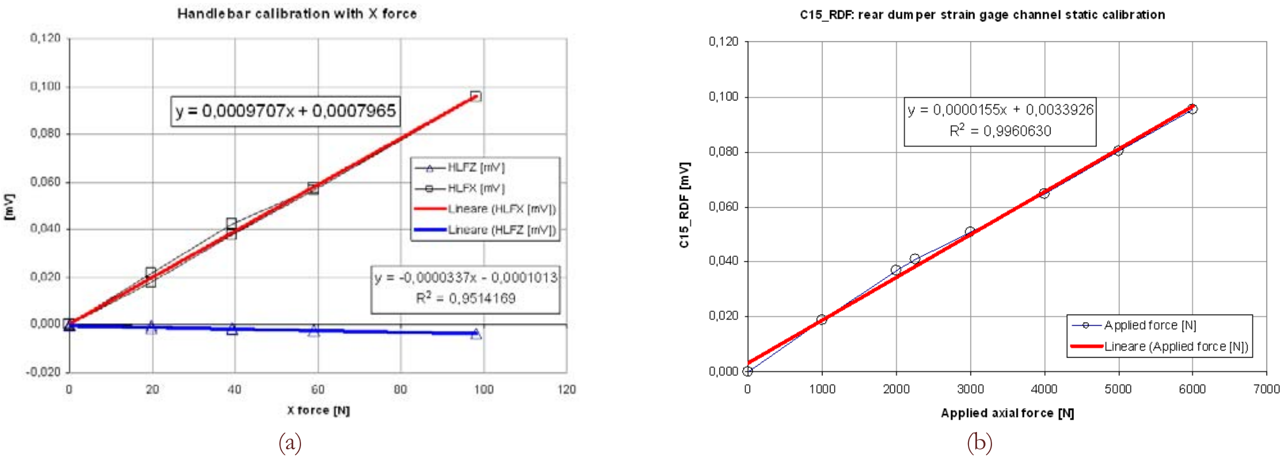
Examples of some calibration test setups are reported in Fig. 2. Plots of the calibration results are presented in Fig. 3.

| Ch. N° | Channel description | Name | Unit | Sensor type |
|---|---|---|---|---|
| 1 | Front Fork Tube Right | C 01_FFR | [Nm] | Half bridge strain gage |
| 2 | Front Fork Tube Left | C 02_FFL | [Nm] | Half bridge strain gage |
| 3 | Front Brake Force | C 03_BF | [N] | Half bridge strain gage |
| 4 | Front Fork Stroke | C 04_FFstk | [mm] | Linear Potentiometer (150mm) |
| 5 | Front Wheel Accelerometer, Z' direction | C 05_FWaZ | [g] | Capac. Accelerometer (100g) |
| 6 | Front Wheel Accelerometer, X' direction | C 06_FWaX | [g] | Capac. Accelerometer (100g) |
| 7 | Handlebar Left Force Z direction | C 07_HLFZ | [N] | Half bridge strain gage |
| 8 | Handlebar Left Force X direction | C 08_HLFX | [N] | Half bridge strain gage |
| 9 | Frame (Telaio) bending moment | C 09_TBM1 | [Nm] | Full bridge strain gage |
| 10 | Frame (Telaio) upper axial strain | C 10_TUA | [μe] | Full bridge strain gage |
| 11 | Frame (Telaio) lower axial strain | C 11_TLA | [μe] | Full bridge strain gage |
| 12 | Front Vertical Force on Saddle | C 12_SFV | [N] | Half bridge strain gage |
| 13 | Rear Vertical Force on Saddle | C 13_SRV | [N] | Half bridge strain gage |
| 14 | Rear Damper Stroke | C 14_RDstk | [mm] | Linear Potentiometer (50mm) |
| 15 | Rear Damper Force | C 15_RDF | [N] | Half bridge strain gage |
| 16 | Rear Brake Force | C 16_BR | [N] | Half bridge strain gage |
| 17 | Rear Wheel Accelerometer Vertical | C 17_RWaZ | [g] | Capac. Accelerometer (100g) |
| 18 | Rear Wheel Right Force Z direction | C 18_RWRFZ | [N] | Half bridge strain gage |
| 19 | Rear Wheel Right Force X direction | C 19_RWRFX | [N] | Half bridge strain gage |
| 20 | Velocity Sensor | C 20_Speed | [km/h] | Native Tmax Inductive sensor |
| 21 | Distance | C 21_Dist | [m] | Digital counter |

Table 1: list of channels applied to scooter Yamaha TmaxS.

(a) (b) (c)

Figure 2: examples of calibration tests on scooter Yamaha TmaxS. (a) Front fork and Frame channels calibration. (b) Handlebar Horizontal calibration. (c) Rear Damper tensile calibration.



(a) (b)

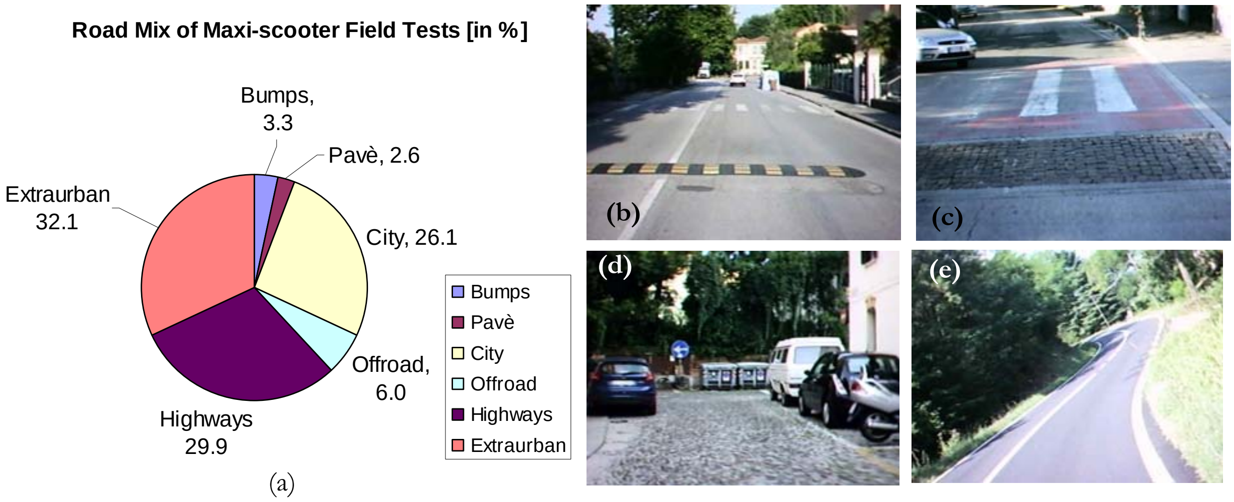
Figure 3: examples of calibration tests results with sensitivity values obtained by linear regression from TmaxS channels output. (a) Handlebar Horizontal calibration tests (Fig. 2.b). (b) Rear Damper calibration tests (Fig. 2.c).

As it can be appreciated from the plots of Fig. 3, the strain gauged components presented in general a good linearity and sufficient load decoupling for the purpose of the study.

## FIELD LOAD ACQUISITION

The field load acquisition sessions were carried out by two expert riders on the instrumented scooter TmaxS. An IMC Cronos PL3 was placed in the helmet housing and collected 16 analog channels at 1 kHz per channel for each run. An onboard camera was placed on the scooter windshield for filming each driving event and surface.

The Road Mix assumed for the study is summarized in Fig. 4.a. The mix was obtained mainly by combining city driving (Fig. 4.b.c.d), extraurban (Fig. 4.e), highway and a small amount (6%) of offroad driving, as the target was the European market. The city driving included a 2,6 % of city pave (Fig. 4.d) and a 3.3 % of bumps that were collected both using the typical 3M™ bumps (Fig. 4.b) and the pedestrian crossings (Fig. 4.c). A total amount of 270 km were recorded: 83 % of them were collected with two persons on the vehicle.



(a)

Figure 4: field tests information. (a) Road Mix adopted for the study. (b) Example of 3M™ road bump encountered in city runs. (c) Example of pedestrian crossing encountered in city runs. (d) Example of city pavè. (e) Example of extraurban driving road.

Results of the field tests were the raw signals from all the scooter components: they were zeroed, verified in terms of spikes and zeroing errors, converted into mechanical quantities such as loads, strokes, acceleration or strain. Further analysis of data regarded the searching for special event that could be significant for defining the component strength static tests. The results of this analysis have been collected for four channels in Tab. 2 and 3. The MAX and MIN values correspond to the positive and negative peaks recorded during the event (bumps & braking) or the portions of tracks that were recognized as representing the different surfaces and conditions (1 person or 2 persons). RNG values correspond to the maximum range values recorded during the considered track portion and correspond to the largest cycles that the components underwent during their recorded fatigue life history. Events with the largest ranges are reported as bold in the table. AVE correspond to the mean values recorded during the track portion, as well as STD correspond to the standard deviation from the track portion.

| | **Bending moment at front fork FFR_C 01 [Nm]** | | | | | **Horizontal force at the handlebar HLFX_C08 [N]** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **EVENT** | **MAX** | **MIN** | **RNG** | **AVE** | **STD** | **MAX** | **MIN** | **RNG** | **AVE** | **STD** |
| Bump 3M 1P (50 km/h) | 1097 | -720 | 1817 | 243 | 120 | 133 | -156 | 289 | 6 | 27 |
| Bump 3M 2P (50 km/h) | 957 | -351 | 1308 | 265 | 92 | 183 | -105 | 287 | 8 | 26 |
| Pedestrian Bump 1P | 777 | -267 | 1044 | 244 | 70 | 170 | -171 | 341 | -12 | 38 |
| Pedestrian Bump 2P | 838 | -233 | 1071 | 270 | 74 | 162 | -89 | 251 | 7 | 25 |
| Front Brake 2P | 760 | -1187 | 1947 | -450 | 622 | 322 | -27 | 349 | 184 | 130 |
| Rear Brake 2P | 490 | 212 | 278 | 394 | 49 | 224 | -40 | 263 | 142 | 48 |
| Pavè 1P | 947 | -1482 | 2429 | 176 | 189 | 407 | -203 | 610 | 0 | 49 |
| Pavè 2P | **1151** | **-1747** | **2898** | 208 | 164 | **446** | **-216** | **663** | -7 | 42 |
| Highway 2P | 671 | -102 | 773 | 256 | 35 | 38 | -56 | 94 | -14 | 10 |
| Urban external ring 2P | 1329 | -1070 | 2399 | 251 | 60 | 170 | -107 | 277 | -9 | 17 |
| Offroad | 814 | -235 | 1049 | 253 | 111 | 175 | -124 | 298 | 13 | 36 |
| Deep Pothole | 731 | -367 | 1097 | 249 | 135 | 298 | -304 | 603 | 10 | 63 |

Table 2: Max, Min, Range, Mean and StDev values of channels FFR and HLFX across the different types of tracks and events.

| | **Bending moment at front frame TBM_C 09 [Nm]** | | | | | **Rear damper force RDF_C 15 [N]** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **EVENT** | **MAX** | **MIN** | **RNG** | **AVE** | **STD** | **MAX** | **MIN** | **RNG** | **AVE** | **STD** |
| Bump 3M 1P (50 km/h) | 1569 | -488 | 2057 | 559 | 137 | 10241 | -1535 | 11777 | 4225 | 1110 |
| Bump 3M 2P (50 km/h) | 1460 | -195 | 1655 | 576 | 123 | 11992 | -1462 | 13454 | 6650 | 1204 |
| Pedestrian Bump 1P | 1344 | -153 | 1497 | 572 | 128 | 10732 | -1209 | 11941 | 4620 | 1484 |
| Pedestrian Bump 2P | 1263 | 8 | 1256 | 614 | 106 | 15529 | 1722 | 13807 | 7479 | 1634 |
| Front Brake 2P | 1086 | -804 | 1890 | -89 | 592 | 8983 | 3881 | 5102 | 5517 | 1437 |
| Rear Brake 2P | 930 | 521 | 410 | 762 | 69 | 9584 | 6587 | 2998 | 8232 | 528 |
| Pavè 1P | 1347 | -1167 | 2515 | 487 | 198 | 9035 | -763 | 9799 | 4376 | 843 |
| Pavè 2P | **1740** | **-1328** | **3068** | 534 | 166 | 12985 | -971 | 13956 | 6383 | 886 |
| Highway 2P | 1015 | 180 | 836 | 595 | 46 | 9641 | 4311 | 5330 | 7375 | 327 |
| Urban external ring 2P | 1740 | -887 | 2627 | 588 | 73 | 11834 | -688 | 12523 | 6679 | 527 |
| Offroad | 1255 | 107 | 1148 | 703 | 132 | 12305 | 242 | 12063 | 7056 | 1287 |
| Deep Pothole | 2141 | 112 | 2029 | 674 | 211 | **40057** | **-372** | **40428** | 7468 | 2614 |

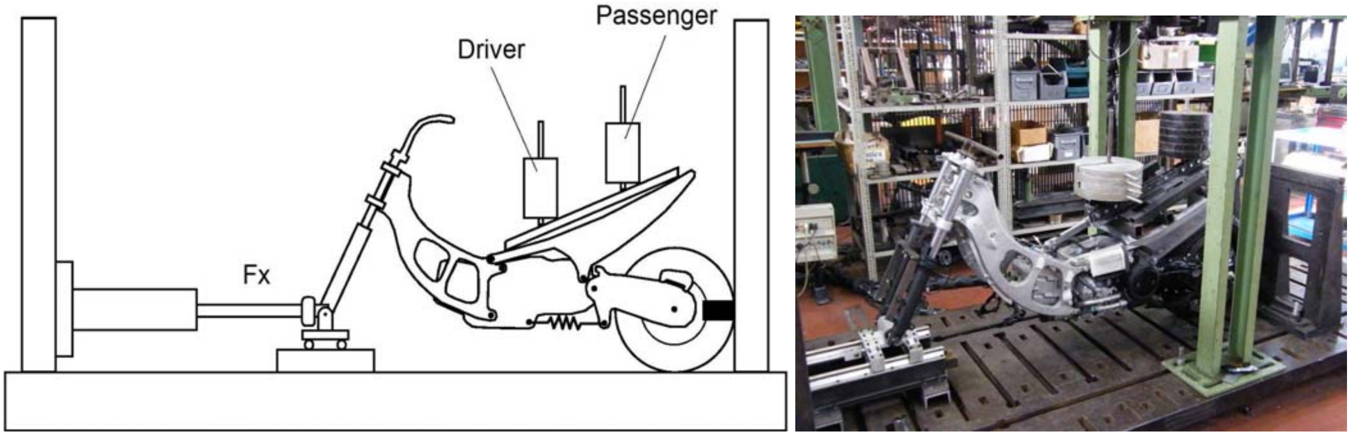
Table 3: Max, Min, Range, Mean and StDev values of channels TBM and RDF across the different types of tracks and events.

## LABORATORY FATIGUE TEST SETUP

### *Horizontal Test Bench Description*

The scooter TmaxS was assembled on the Fatigue Test Bench as shown in Fig. 5.a. The frame was loaded by the FX force (Bench FX Force) at the front fork axle, after locking the front fork excursion at the static nominal length. Loads were applied by means of a 15 kN MTS 242 hydraulic cylinder. The Cylinder was under Force Control by the MTS TESTAR II m system. Deadweights were applied at the rider (95 kg) and passenger (85 kg) locations as indicated by the manufacturer in order to reproduce the static Frame Bending Moment at Channel 9 (TBM). This channel was eventually adopted as the master channel to be taken as the reference channel: being able to reproduce the bending moment load history at channel TBM was assumed to be stressing the frame-fork connections and the frame-engine connections in an equivalent manner.

The frame front fork axle was fixed on a horizontal slider. The rear wheel (inflated at prescribed pressure) was clamped on a rigid plane applied to the bench, after preloading the tyre with 5000 N. The rear damper was substituted by a stiff rigid rod of the same dimensions.



(a) (b)

Figure 5: Horizontal fatigue test bench (a) Sketch of the Horizontal Fatigue test bench. (b) Yamaha TmaxD undergoing the horizontal fatigue test.

### *Overall Description of the Variable Amplitude Fatigue Test Procedure*

The test procedure was defined by combining the information collected during the Field Tests and the Laboratory Calibration tests with the required Target Fatigue Life and the Bench Fatigue Tests data. The overall procedure can be divided in several steps of the study.

1. Field Data Analysis
   a. The strain data recorded in the Field at Channel #9 (TBM), (Field Measured Signals), corresponding to the Front Frame bending moment at a significant location (down tube of TmaxS), were used as reference data.
   b. The Field Measured Signals from the different available road tests were joined to obtain a total track of 270 km, corresponding to a total recorded time of 518.74 min (8,645 h).
   c. The Field Measured Signals was rainflow counted (Range Only method) to produce the Field Measured Spectrum.
   d. The Field Measured Spectrum corresponding to 270 km was extended for $NB^{TL}$= 185 times to reach 50000 km Target Life.
   e. The extended spectrum corresponding to 50000 km was compared with a Virtual Fatigue Curve of a welded frame with Wohler exponent k=4, as from previous experience with welded motorcycle frames and components [10,16]. Linear Damage Summation and Miner rule were used to estimate the minimum required Frame strength corresponding to a Target Life of 50000 km.

f. The results of such analysis were that the Virtual Fatigue Curve corresponding to a life of 50000 km would be described by a slope of k=4, and a Reference range of $\Delta$TBM [Nm] = 906 Nm at 2 $10^6$ cycles.

## 2. Test Acceleration Procedure

a. To reproduce the Field Measured Signals corresponding to 270 km up to the required life of 50000 km with a 1:1 time scale, a total number of 1599,3 hrs would have been needed. This test duration would not be sustainable; therefore a Test Acceleration Procedure was developed.
b. Test acceleration was obtained by means of the following actions: (i) Peak-Valley counting of Field signals, (ii) generation of Command Signal, (iii) interpolation of command peaks & valleys, (iv) amplification of Command signals, (v) reproduction of command signals.
c. Peak Valley counting was performed on the Field Measured Signal of TBM using a Hysteresis threshold of 494 Nm (corresponding to the 16% of the maximum recorded range of TBM), leading to a Total Fatigue damage reduction from 1.0 to 0.9. This allowed to reduce the Field Measured Signal of TBM to a peak-valley signal containing a total number of 11604 peaks and valleys.
d. The TBM signal was converted into a horizontal force signal FX by means of the Transformation constant obtained during static calibration on the TmaxS scooter after application of FX forces and recording of TBM signals. The result was a peak-valley signal that could be used to Command the Bench.
e. For the bench variable amplitude fatigue, the sine interpolation of peaks and valley was adopted as implemented in the MTS control: this produced a sinusoidal command file where peaks were reproduced at an average frequency of 7 Hz.
f. The MTS control was tuned with the PID values in order to match the Applied Loads with the Command Loads. To help this procedure, due to the hydraulic PID control and the test frequency, an amplification factor of 1.22 was introduced to optimize the applied FX signal.
g. The result of this procedure was that a block corresponding nominally to 270 km could be reproduced with a nominal duration of 30 minutes. The Target Life of 50000 km could be nominally reached after application of 185 blocks, corresponding to duration of 90 hrs.
h. The Force FX really applied to the frame was recorded during the test as Bench Measured Signal FX. This was different from the target signal. To take into account these differences, the TBM signal measured on the TmaxS mounted on the bench was recorded, rainflow counted and compared with the reference Virtual Fatigue Curve.
i. The number of Blocks needed for a fatigue damage equivalent to 50’000 km was then recalculated based on the ratio between the Road Measured Damage and the Effective Bench Measured Damage. This lead to increase the initially estimated number of 185 Blocks to a number of 245 blocks to be applied (corresponding to duration of 122 hrs).

### *Vertical Test Bench Description*

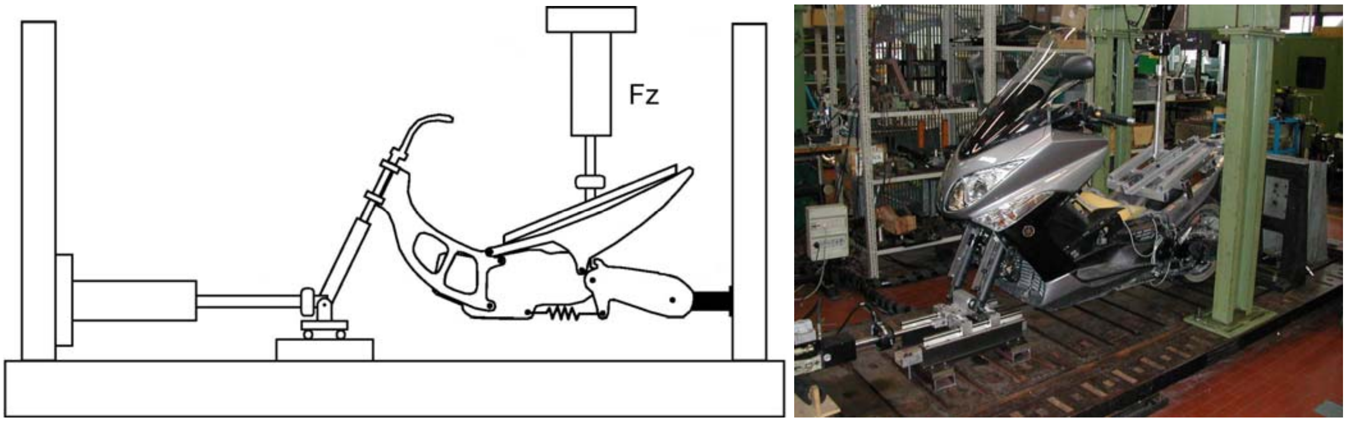
The scooter was assembled on the Fatigue Test Bench as shown in Fig. 6.a. The frame was loaded by the SFZ force (Bench SFZ Force) on the saddle structure. Loads were applied by means of a 15 kN MTS 242 hydraulic cylinder joined on a customized loading structure positioned over the rear frame without stiffening effects. The cylinder was under force control by the MTS TESTAR IIm system. No deadweights were applied in this case: the mean value of saddle loads was obtaind by the mean value of the actuator. The frame front fork was fixed on a horizontal slider, with free displacement in x direction, zero load control. The frame rear axle was fixed on a rigid post applied to the bench.

Particular care was adopted in the definition of the vertical load SFZ location: static calibrations with vertical loads were applied to the saddle at three different locations: the driver, the passenger and an intermediate. This allowed to compare the relative response of channels C_12 and C_13 during static calibrations and to locate the cylinder at a representative location able to stress adequately the saddle upper frame and the rear suspension.

Channel C 18_RWRFZ was adopted as the master channel for the convergence of the vertical variable fatigue tests: being able to reproduce a vertical load history at channel RWRFZ was assumed to be stressing the rear swing arm, the swing arm connections to the engine, the saddle frame and its connections to the engine in an equivalent manner.

### *Vertical Fatigue Test Procedure*

The strain data recorded in the Field at Channel #18 RWRFZ, corresponding to the Rear Wheel Force measured at the axle, were used as reference data. This signal was available only from the TmaxS vehicle. So, after converging with the damage calculated at RWRFZ on the TmaxS scooter, following the same acceleration procedure presented for the horizontal fatigue test, the saddle force history SFZ was saved and reapplied to both the TmaxD scooter and the prototype P1.



(a) (b)

Figure 6: Vertical fatigue test bench. (a) Sketch of the Vertical Fatigue test bench. (b) TmaxS undergoing the vertical fatigue test setup.

## VARIABLE AMPLITUDE FATIGUE TESTS

The variable amplitude fatigue tests were performed up to the target life of 50'000 km on two maxi-scooter frames. Both the Horizontal and Vertical variable amplitude fatigue tests were performed in sequence on the TmaxD scooter and on the prototype scooter P1. The failure criteria was assumed as the presence of 10 mm visible cracks at any location of the frame. The components were periodically visually inspected during working hours.

The frame stiffness decrease along the tests was in parallel considered as an indicator of failure, due to an increased compliance of cracked components. The 20 % reduction of initially settled stiffness was adopted as the test stop.

As a results of the fatigue tests on the TmaxD frame, no failures were detected at the main frame, the swingarm nor the saddle frame. This was corresponding to the expectations as the scooter was a very well established product, circulating worldwide in the market since several years and was chosen by the manufacturers as a benchmark competitor.

Differently, the Prototype P1, at its very early stage of development, presented a few localized failures during the vertical fatigue stage: after a variable amplitude fatigue equivalent to 15600 km, a bolt failure was experienced at the connection between the saddle frame and the mainframe. This resulted in the decision by the manufacturer to increase the diameter of all connection bolts at that location.

The prototype did not show any stiffness decrease after the variable amplitude laboratory tests nor visible cracks were detected at any accessible component: the road tests campaign with drivers was then permitted and drivers started to test the behaviour of all motorcycle components, from the fork-frame assembly to the engine and cooling systems, from the braking systems to the electric components.

Interestingly, after 50'000 km of road tests on a fully equipped prototype, while investigating about the wear of different component on a fully disassembled vehicle, manufacturers discovered the presence of a small crack at the foot of the fillet of a reinforcing web in the inner portion of the frame end piece, connecting the rear swing arm to the main frame (Fig. 7.a). The corresponding piece of the prototype P1 that underwent the horizontal and vertical fatigue was then reanalysed after disassembly: effectively, at the corresponding location of the frame end piece, a small crack of 5 mm depth was observed and confirmed subsequently by dye penetrant inspection (Fig. 7.b). This evidence, initially not captured during the overall visual crack inspection nor revealed by any stiffness reduction of the assembly, confirmed the ability of the developed procedure to reproduce the fatigue damage accumulated by the vehicle during the 50'000 km test drive in the accelerated laboratory tests.

As a result of this evidence, design engineers modified the fillet radius at the web and on following prototypes and series vehicle the new component presented a modified shape, as shown in Fig. 7.c: the following drive and bench tests never produced cracks at that location (Fig. 7.c).

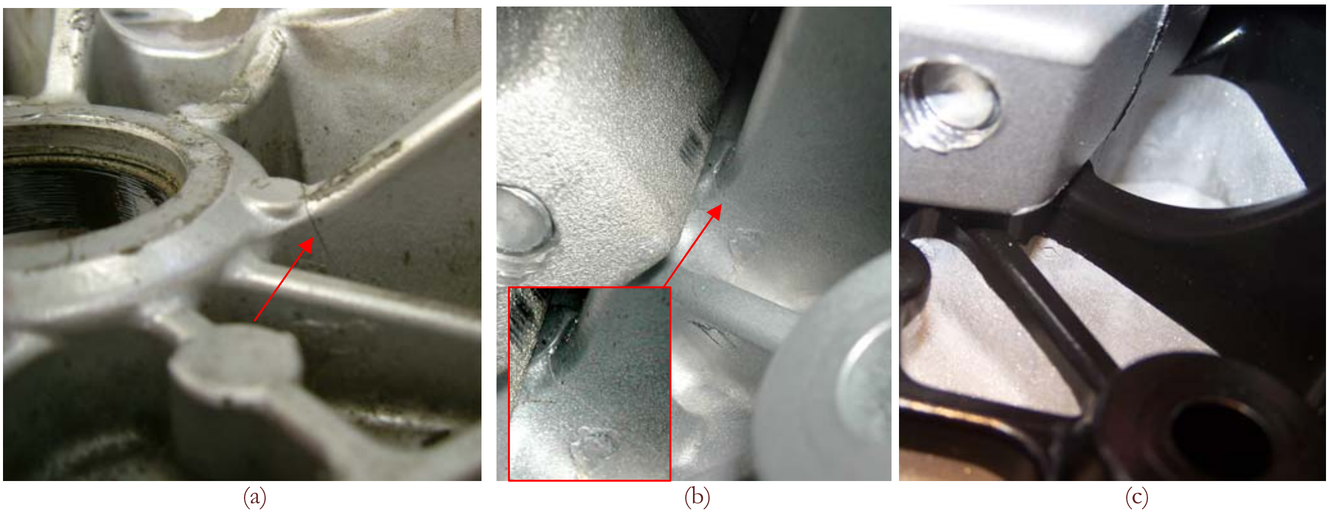

(a) (b) (c)

Figure 7: crack detection and redesign. (a) Crack detected after disassembly of prototype undergoing 50000 km drive tests. (b) Crack detected at the same location after 50000 km equivalent variable amplitude fatigue bench tests. (c) Modified component with increased fillet radius to avoid stress concentration.

## DISCUSSION

The fatigue design and testing of motorcycle components is a complex task regarding which most manufacturer usually develop a complete procedure consisting of field data acquisition, fatigue life estimation and fatigue bench testing, based on former experiences: these information are rarely available or are supplied by specialized companies once expensive test bench and control software are purchased [15] together with even more expensive dynamometric hubs to be applied at the wheel axles [6].

The present work intended to give a contribution regarding the complete approach to the problem, by presenting step by step the procedure and describing some passages in detail, similarly to what was performed on a simpler case such as the seatpost of a mountain bike experiencing a general recall after field failures [4]. It can be adopted by manufacturers, designer, test institutes in developing an accelerated test procedure.

The main limitation of the study was its single axis testing approach. The horizontal and vertical testing were performed in sequence: more sophisticated methods (based however on dummy loaded motorcycles) are able to synchronously reproduce the field load histories on different components of the motorcycle. These benches however require in any case a similar procedure for the acceleration of the test.

The method proposed can be unified in a single test provided that the damage contribution on the two master channels considered for the horizontal and the vertical test tuning will be arriving to the same summation after each block.

In addition to that, the availability of poor components of short field fatigue life is very useful in the tuning of the method, as their known finite fatigue life will be assessed in the accelerated tests, therefore confirming the overall procedure as it happened with the present prototype frame.

## CONCLUSIONS

A Tmax maxi-scooter was equipped with 22 channels applied to the scooter main components such as frame, fork, handlebar, rear frame and suspension. Service loads were collected during 270 km of field tests including city, extraurban, highway and offroad riding in order to represent an assigned road mix. Field load histories were used to develop an accelerated test procedure for the accelerated bench fatigue testing of a new model prototype whose mission was set to 50000 km. A two stage variable amplitude fatigue test was applied to the benchmark scooter Tmax and to a maxi-scooter prototype P1 under development. The time reduction obtained by implementing the proposed procedure was from 1600 hrs to 122 hrs bench equivalent testing for horizontal test. The results of the fatigue tests on the prototype were validated after the appearance of small cracks at a notched component that were found also after 50000 km of driving tests.

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