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Study on lubrication effect on motorbike chain transmissions

Structured Abstract.

Purpose.

This paper examines motorbike's chain transmission, focusing on chain lubrication and its effect on the temperature, efficiency and vibrations of the transmission.

Purpose of the paper is to compare transmission's performances under three different lubrication conditions: (i) chain not lubricated at all, (ii) chain lubricated with a spray PTFE addicted lube, and (ii) chain lubricated with a mineral oil at every minute of the test.

Design/Methodology/Approach.

An experimental campaign has been performed running a chain under the three above lube conditions at different speeds with the purposes of: (A) measuring the effect that each lube conditions has on temperature, on vibrations and on the efficiency of the transmission, and (B) identify the best conditions for practical use. A test rig has been designed and manufactured for the purpose, and temperature, transmission's efficiency and vibrations have been recorded during the tests by using a thermocamera, a dynamometer and an accelerometer respectively.

Findings.

Results showed that a proper lubrication is desirable. Additionally using a continuous lubrication with a mineral oil lubricant leads to better transmission compared to the use of the spray PTFE from the efficiency and thermal points of view.

Originality/Value

This work presents an experimental investigation on the effect of two different kind

of lubrication form motorbike chain on transmission's efficiency. The findings are still valid for different applications of chain transmission in dirty environments.

Novelty of the paper is following highlighted:

1. this is the first work scientifically facing the important topic of lubrication of chain in dirty environments, particularly of motorbike chain;
2. a complete analysis of thermal and mechanical effect due to presence of lubricant has never been shown;
3. different kind of lubricant have been used and their effect has been separately highlighted.

Keywords: Wear, Testing, Motor Vehicles.

1. Introduction

Chain transmission is one of the widest mechanisms used by designers all around the world, in any fields, for centuries. This paper deals with lubrications of those chains that work in dirty environment, particularly addressing motorbike transmissions.

Chains running in clean environment do often need no lubrication at all, while e.g. motorcyclists experience chain wear and running issues due to environmental impacts contamination and high running temperature, which combined can cause excessive chain elongation, wear, loss of efficiency and overheating. Correct lubrication is important, and a well lubricated chain has longer and safer life (Chen et al., 2006). Despite chain transmission is one of the most important mechanism of a motorbike (and of a many other engine- or human- powered vehicles), few papers can be found in literature scientifically tackling the matter of its efficiency (Lee and Priest, 2004). A number of dedicated magazines have reported on the topic, mainly basing on direct user experience, on how, when, and how often a motorbike chain has to be lubricated (webbikeworld.com/t2/motorcycle-chain-lube/chain-lubes-2010.htm). Many different opinions can be found, but almost nothing can be

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3 found scientifically dealing with the problem.

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5 This lack of scientific evidences on a so common and wide problem is at the
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7 base of the present work, aiming to address untreated aspects for a more
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9 comprehensive study on lubrication and efficiency aspects of chain
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11 transmission in dirty environments.

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13 Motorbike chains are exposed to variable environmental conditions, irregular
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15 loads, transversal vibrations, and environmental impacts such as dusts, dirt,
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17 grit and rain. Lubrication and preventive maintenance can significantly extend
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19 the life-cycle of the component. The purpose of this work is to experimentally
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21 investigate motorbike chains driven under different operative conditions, and
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23 to understand the factors that affect the efficiency of a chain power
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25 transmission.

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27 Few authors have already discussed chain efficiency. Hollingworth and Hills
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29 (Hollingworth, Hills, 1986) presented a theoretical efficiency model of chain
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31 made by cranked links and discussed the number of teeth's effect in open-
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33 and narrow-end forward geometries. Burgess (Burgess and Lodge, 2004)
34
35 showed that at speed higher than 75 MPH the efficiency of the chain strongly
36
37 reduces due to inertial tensions.

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39 The speeds here considered in the present paper are all lower than that
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41 threshold, and results will not be affected by the chain speed.

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43 Lodge and Burgess (C.J. Lodge and Burgess, 2001) presented a model of
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45 roller chain forces and transmission efficiency. They compared their model
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47 with experiments and obtained good results for moderate and high torque
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49 transmissions, while losses due to impact, adhesion and/or vibration impair
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51 the accuracy of the model at low torque.

52
53 Messaadi (Messaadi et al., 2013) presented an experimental study on
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55 boundary lubrication of sintered steel under impact-sliding conditions, very
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57 similarly to what happens in a chain-sprocket system. They found out that the
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59 presence of lubricant changes the wear mechanism from an abrasive-
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adhesive-corrosive process to plastic deformation and crack opening (this

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3 later aspect is not so relevant for non-sintered components such those object
4 of this work).

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6
7 Present paper falls in the low-torque condition, since the driven shaft has
8 been loaded with a 10 Nm torque.

9
10 Pedersen (S.L. Pedersen et al., 2004) simulated roller chain drive system
11 including the impact with guide-bars without any lube, by a multi-body
12 approach.

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14
15 Martin (Martin, 1978) presented a review of traction in gear teeth and showed
16 the trend of friction coefficient under different lube regimes. He also studied
17 that the teeth-chain contacts fall into the partial ElastoHydroDynamic (EHD)
18 lubrication condition, in which there is no interaction of asperities, and friction
19 is a function of fluid properties and, in certain situations, of the surface
20 quality.

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22
23 In their work with bike chains, Spicer et al. (Spicer et al., 2001) indicate that
24 non-thermal loss mechanisms such as chain tension and sprocket size
25 primarily affect efficiency. Their tests have been conducted for bike chain at
26 much lower speed and power than those here presented, but provide
27 interesting analysis of frictional loss mechanism.

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30 In this paper authors approach the problem performing experiments to study
31 the role of the lubricant in motorbike transmission: three sets of chain and
32 sprockets ran 6000 miles under different lubrication condition before being
33 tested at several speeds, while transmission's efficiency, driver sprocket's
34 temperature, and system's vibrations were registered. The effect of
35 lubrication varies from one lubricant to another: in particular Nakajima
36 (Nakajima and Mawatari, 2005) investigated the effect of synthetic and
37 mineral oil on bearing steel rollers. They show that significant differences can
38 be recognized in the distributions of pressure, film thickness and temperature
39 in the region of contact using the two oils, and assessing the best effects
40 given by the mineral one.

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43 While previous work has primarily focused on lab testing this paper adopts a

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4 new approach to the testing methodology. Efficiency of motorcycle chains is
5 heavily depending on their wear which in turn is influenced by the
6 environmental impacts they undergo over time. To mitigate environmental
7 impacts on the chain, lubrication is recommended. Various options for chain
8 lubrication exist such as interval spray lubrication or continuous drip
9 lubrication. To analyse the efficiency of a typical motorcycle chain three sets
10 of motorcycle chains and sprockets will be tested to compare the differences
11 when using available lubrication methods over a longer period of time and in
12 the harsh real-world environment they are typically used in.
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19 Results show a general increase of efficiency when the system is lubricated.
20 Additionally the continuous lubrication with mineral oil leads to better results
21 than the interval lubrication with spray-PTFE. Experiments show that an
22 improved lubrication reduces the friction in the chain and the impacts
23 between parts, improves the efficiency, leads to slightly lower vibration of the
24 system, and a measurable reduction of the chain temperature.
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30 The paper aims of being of practical use for bikers and all the machine users
31 that work with chains in a dirty environment, assessing the vibration and the
32 transmission's efficiency due to different lubricant condition. The study
33 approaches the problem from a macroscopical point of view, focusing on
34 which type of lubrication causes which effect on the global efficiency and on
35 the vibration of a power chain. Outside the scope of the present study is the
36 investigation of what happens at each tribological contact characterizing a
37 power chain (pin-bush, bush-roller and roller-sprocket); nevertheless the
38 results here presented lays an interesting foundation for further works on this
39 topic.
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49 **2. Methods**

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51 The experiments had the purpose to determine the effect of different lube
52 conditions on the global efficiency of the transmission.
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55 Three different lubricants were considered, and a second scope of the work
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3 was to define which lubricant condition is more suitable to increase chain's
4 efficiency and endure its life. Three sets of sprockets and chain have been
5 used, one for each lubricant condition.
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9 The tests ran in laboratory environment, even though the chains were used
10 before experiments in real conditions on the road. The efficiency of the chain-
11 sprockets systems was measured with a torque transducer, and investigated
12 through chain's temperature and rig's vibrations.
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16 In particular the following lube conditions were investigated:

- 17 1. chain without any lubrication;
- 18 2. chain lubricated with commercial GT85 spray lubrication containing
19 PTFE;
- 20 3. chain lubricated with light mineral oil with some corrosion inhibiting
21 additives. In particular the lubricant was made of highly refined mineral
22 oil (>80%), proprietary preparation (<5%), 1 H-imidazole-1-ethanol 4,5
23 (<5%) and -dihydro, 2-C15-C17 alkyl (<5%).
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30 Each set ran 6000 miles prior the tests in daily weather condition, on the
31 same route, on a bike driven by the same driver, under the lube condition
32 they would have been tested later. In other words, set 1 ran 6000 miles
33 without any lubrication, set 2 ran the same mileage regularly lubricated with
34 GT85 lube every 300 miles, and eventually set 3 ran 6000 miles regularly
35 lubricated every minute with light mineral oil, using an automatic chain oiler,
36 Set 2 was not lubricated during the tests, since the use of PTFE spray is
37 recommended every 300 miles, which means every 6 hours at an average
38 speed of 50 MPH: the tests ran for much shorter time, and therefore lubricant
39 was not necessary. On the other end, set 3 was lubricated by using the
40 Scottoiler chain oiler eSystem shown in Figure 1 to maintain the same lubricant
41 condition during the 6000 miles run.
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53 Figure 1
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4 The oiler leaked 1 drop of lubricant every minute, and its position is shown in
5 Figure 1.
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7 The driver rode the motorcycle with chain and sprockets to be tested to and from
8 work every day: it is 150 miles return trip always following the same road in order
9 to keep the same influencing factors. Environment factors such as salt, water, dirt,
10 etc..., which change by the seasons, are taken into account by changing over the
11 chains and the sprockets every 1500 miles, which, 150 miles per day, means
12 roughly every 2 weeks. So through changing the chains and sprockets it has been
13 ensured that all the chains had the same environmental impacts.
14

15 All the chains were Tsubaki Omega ORS sealed O-ring steel model, with 116
16 links and 525 pitch. Chain came with high viscosity grease vacuum injected
17 internally by the manufacturer. Drive sprockets were Renthal, 17 teeth, CNC
18 machined in case hardened Nickel-Chrome-Molybdenum steel. Gearbox
19 sprockets were JT, 41 teeth, in High Carbon steel. The global gear ratio
20 $I = \omega_{\text{driver}} / \omega_{\text{driven}}$ was 2,41.
21

22 Tests were performed in a home-designed rig manufactured for the purpose
23 (see Figure 2(a)). The rig was designed to allow the distance between the
24 two shafts to be adjusted, in order to maintain the same chain tension during
25 all the three experiments. A torque wrench was used to move back/forward
26 the position of the bearings of the driver shaft and to give the three sets of
27 chains the same tension.
28

29 The tests were undertaken using a 75 kW motoring rig at the Energy
30 Technology Centre in East Kilbride (UK) fed with a variable speed DC motor.
31 The driven sprocket is connected via a driveshaft to an eddy current
32 dynamometer. The chain being tested is fitted to the two sprockets and
33 transmits power from the motor to the dynamometer, ensuring that the chain
34 runs under load. The speed of the driven sprocket was measured using an
35 optical sensor applied to its shaft. The torque at the driver sprocket was
36 measured by a dynamometer, and the speed by using an inductive pickup
37 and toothed wheel.
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Each set of chain and sprockets ran at 3 different speeds, simulating a motorbike speed of 41, 50 and 70 MPH (66, 80.5 and 112.6 Km/h respectively); considering an outer radius of the motorbike wheel of 600 mm, the driven shaft spun at 581, 705 and 995 RPM respectively, which give for the driver shaft a speed of 1400, 1700 and 2400 RPM respectively.

Each tests had a warm-up period of 15 minutes at 1250 RPM before collecting data at the above speeds.

During the tests three set of measures were taken:

1. temperature of the driver sprockets, by using a LAND ARC 8-22-1000 thermo- camera (see Figure 2(b)). The thermos-camera faces the sprocket running at the highest speed, i.e. the one reaching the highest temperature. Temperature is measured with an accuracy of 2%. The camera records a video, which is then processed with the free software Hex Editor Neo (www.new-hex-editor.com). It allows, frame by frame, determining the temperature of any point of interest. By measuring the temperature of the same point throughout the video, it is possible to determine its trend vs time;
2. vibration of the system, by an accelerometer placed to the driver shaft's support (see Figure 2(b)). The sensor was a Reactec's magnetic piezoelectric accelerometer with an RT-440 module: it has a dynamic range greater than 90 dB, frequency range between 2 and 40 kHz, automatic Fast Fourier Transform (FFT), of 100 to 12800 lines and time block length of 256 to 32768 samples. The instrument allowed recording the signal in both time and frequency domains. Vibrations were recorded multiple times during each test, with different frequency ranges and sampling;
3. efficiency of the transmission, by measuring the torque applied to the driver shaft (T_{driver}) necessary to maintain the speed, given the 10 Nm torque to the driven shaft ($T_{\text{driven}} = 10 \text{ Nm}$). Efficiency (η) were determined as $\eta: T_{\text{driver}} / (T_{\text{driven}} \cdot I)$.

Figure 2

The measurements were used to gather information to compare the three sets of sprockets and chains and in particular to investigate the effect of the lube condition on the performance of the transmission.

A 10 Nm torque applied at 2400 rpm leads to 2.5kW of power, which is quite low compared with the power a standard motorbike, but the choice of those values was forced by the configuration of the test rig. Sprockets were linked to the motor and to the dynamometer by two long steel shafts, as shown in Figure 2: the RPM was meant to be high enough to simulate real speed, and the torque was set up as high as possible: unfortunately an higher value would have generated unwanted noise vibrations that would have significantly jeopardize the quality of the results. The authors had to find a compromise between speed and torque, and decided to maintain high speed and so reducing the torque.

3. Results

3.1 Efficiency

The efficiency of the system was calculated as explained in §1.3: 10 Nm torque was applied to the driven shaft and the overall efficiency of the system was calculated by measuring the torque at the driver shaft.

Results are shown in Figure 3 and presented in Table 1.

Figure 3

Table 1

A general increase of efficiency is shown with both the lubricant for the 1250, 1400 and 1700 RPM speeds. In particular a continuous lubrication with

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3 mineral lubricant oil significantly reduces the waste of energy of the system.
4 Even if the error bars are quite large, the improvement of the global efficiency
5 of the system can be clearly observed. From the results it also appears that
6 at high speed the efficiency of the system lubricated with light mineral oil lube
7 seems lower than that at the other two configurations. It is due to the fact that
8 at high speed the vibrations induced a significant fluctuation of the measured
9 torque, as also shown by the error bars in the chart. A series of reading have
10 been taken in order to reduce the error.

11
12 Despite the errors, it is clear that the use of lubricant increase the efficiency
13 of the system, by an estimated average of 4.1%. In particular the continuous
14 lubrication with a light mineral oil allows the best performances: the system
15 has efficiency of 3.6% and 4.1% higher than that of an interval spray-
16 lubricated and non-lubricated system respectively.

27 28 3.2 Vibrations

29 For each speed and lube conditions, the acceleration times gravity's constant
30 of the measuring point have been recorded in time domain. In particular, after
31 tuning the sensor's parameters to obtain the clearest results, rig's vibrations
32 have been recorded using a frequency range of 1 kHz, collecting 512
33 samples for 0.2 seconds; resolution was 5 Hz.

34 Results of vibration investigation are shown in Figure 4 and Table 2,
35 presenting the Root Mean Square (RMS) value of each recorded signal.

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45 Figure 4

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51 RMS estimates the noise of a signal and gives information about the
52 smoothness of a vibration. The lower the RMS, the less noise is registered
53 by the sensors. For the practical purposes of this paper, low values of RMS

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3 mean less vibration for the biker and better comfort during the drive.

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5 From the chart, the effect of the lube is clearly shown: the noise content of
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7 the vibrations is significantly reduced by using lubrication, especially at the
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9 highest speed. Furthermore the chain and sprockets that were continuously
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11 lubricated using a mineral oil lube seems to be slightly more effective than
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13 the set of chain and sprockets that were lubricated at fixed intervals every
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15 300 miles.

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17 Another set of signals has been recorded, by using the capability of the Rt-
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19 440 of recording the FFT of the vibration: for each configuration the Fourier
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21 Transform of the signals has been recorded in the range of 0-4000 Hz,
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23 acquiring for 0.05 seconds, and presented in Figure 5

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25 Figure 5

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28 As expected the spectrums present an increasing noise with the speed, but
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30 there clearly are some differences between the three configurations.

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32 At all the speeds, the two lubricated configurations follow the same trend,
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34 throughout the whole frequency range, and the main difference is the lower
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36 amplitude registered with mineral oil compared to the PTFE one.
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38 Furthermore, at 1400 RPM and 2400 RPM mineral oil's spectrums appear
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40 much smoother than the other two, confirming the reduced noisy vibration
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42 content already shown in Figure 4.

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44 The reduced number of peaks of lubricant configurations compared to the
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46 non-lubricated one is a clear proof of the effectiveness of the lubricant in
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48 reducing the vibration content of the transmission.

49 50 3.3 Temperature

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52 As introduced above, the chains have been warmed up for 15 minutes at
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54 1250 RPM, then ran 5 minutes at each one of the 1400, 1700 and 2400
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56 RPM: the temperatures were measured at the end of each time batch, in

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4 order to allow the temperature to stabilize. Temperature was measured by an
5 infra-red camera pointing the front sprocket and the representative pictures
6 are reported in Figure 6.
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9 Due to the disassembly and assembly operations required between two sets
10 of chains, the whole system had the time to cool down after each run, and all
11 the tests started with all the components at room temperature. Each test
12 lasted for 45 minutes approximately, including assembly and disassembly
13 operations, thus all the experiments took less than 3 hours: the room
14 temperature can be considered to be the same during the whole set of
15 experiments which all started under the same conditions.
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23 Figure 6
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26 Images have been then processed with Hex Editor software, which enables
27 to extract the temperature of any point of the picture. In Table 3 the
28 temperatures of the chains measured during the tests have been presented.
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30 The camera pointed the running chain close to the driver shaft, and Figure 7
31 presents the temperature of each chain normalized in comparison to the
32 temperature of the non-lubricated set of chain and sprockets.
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42 Figure 7
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46 It is shown that the presence of lubricant has a significant impact from a
47 thermal point of view, and significantly cools down the temperatures of the
48 chain. It is also shown that the two lubricants give different results: in
49 particular, even if spray lube contains PTFE, which significantly reduce the
50 friction between two brushing parts, the mineral oil proved to better dissipate
51 the heat generated by the transmission.
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4 The lower chain temperature is also supported by the continuous lubrication
5 enabled through the mounted chain oiler system that feeds 1 drop of
6 lubricant into the chain for every minute of the test.
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9 Table 3, in particular, shows that the mineral oil lube dissipates averagely
10 about 80% more heat than the spray one.
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13 14 **4. Discussion**

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16 Lubrication of chain power transmission is a matter of absolute importance
17 not only for ensuring reliability, but also for the efficiency of the chain drive.
18 Experiments presented here showed that lube plays an important role in heat
19 exchange and vibration during the chain run and thus in the overall efficiency
20 of the system, here studied from both mechanical and thermal points of view.
21 Chains working in high temperature environments become hotter and their
22 length increases at about the same ratio as its coefficient of linear expansion
23 (Tsubakimoto Chain Inc.), leading to lower tensioning, higher vibrations,
24 higher wear and lower efficiency. The experiments here presented show that
25 a correct lubrication can significantly reduce the amount of heat generated
26 during the motion: it is not clear yet whether the lubricant reduces the
27 intensity of the impacts between the brushing component of the chain during
28 the motion or simply absorbs the heat generated by the contacts, but results
29 presented in §3.2 certainly suggest a contribution on the impacts. As
30 introduced by (Martin, 1978), friction between parts is a function of fluid
31 properties, and it explains that both the lubricated systems present the same
32 trends in terms of vibrations and heat exchange, even if with different results.
33 The lubricant reduces the impacts between parts, leading to a reduced noise
34 and vibrations, with benefits for the transmission and thus for the driver
35 comfort (in case of motorbike application). Figures 4 and 5 show that,
36 especially at high speeds, the presence of a lubricant is very important: it
37 reduces the intensity of the contacts during the motion, leading to a much
38 smoother transmission. Table 2 indicates that the noise level of a lubricated
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3 system is closely linear with the speed, while for non-lubricated system,
4 vibrations become significantly high after a certain speed.
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7 Frequency spectrum of the vibration acquired during the tests show the
8 effectiveness of the lubricant in reducing vibration through the investigated
9 spectrum (0-4000 Hz), for all the speeds.
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12 The benefits experienced through different forms of lubrication and analysed
13 in this study from thermal and mechanical points of view are the principal
14 responsible of the improvement of transmission efficiency. A 4%
15 improvement addressed only to lubricant is impressive, and further studies
16 will follow to optimize lubricant formulation and composition to increase its
17 impact.
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23 24 25 **5. Conclusion**

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27 In this paper lubrication of motorcycle chains and its impact on power
28 transmission has been analysed. Mechanical efficiency, vibration and
29 temperature have been measured on 3 different sets of sprockets and chain,
30 each one running under different lubrication methods, with the purpose of
31 studying how lubricant affects the transmission. Results prove that lubrication
32 has a significant impact on the efficiency of the system, mainly acting on the
33 following aspects:
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- 39 • the use of lubricant leads to 40% slower temperature increment of the
40 chain during the motion, and chain temperature during operation is
41 reduced by up to 5% thus reducing chain elongation and wear and
42 improving chain efficiency.;
- 43 • vibration is reduced; the RMS is about 50% lower when the
44 transmission is lubricated, reducing the wear of the chain due to a
45 softer impacts between the brushing chain and sprockets, and
46 improving the comfort for the driver;
- 47 • the transmission results significantly smoother in the 0-4kHz spectrum
48 when lubricant is applied;
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- chain efficiency is up to 5% higher when lubricated, due to reduced vibration and temperature rising.

Further improvements can also be observed when comparing the different lubrication methods. By using a continuous lubrication with light mineral oil as a lubricant the improvements are higher than using an interval spray lubrication with PTFE. A continuous lubrication is capable of reducing the chain temperature compared to a spray lubricated chain.

Despite the limitation of the low load condition, this paper represent a significate starting point for further works to investigate the contribution of thermal and non-thermal efficiency loss during the motion, and the contribution of each of the three tribological contacts present in a roller chain. An Acoustic Emission analysis is also planned in order to deepen the investigations.

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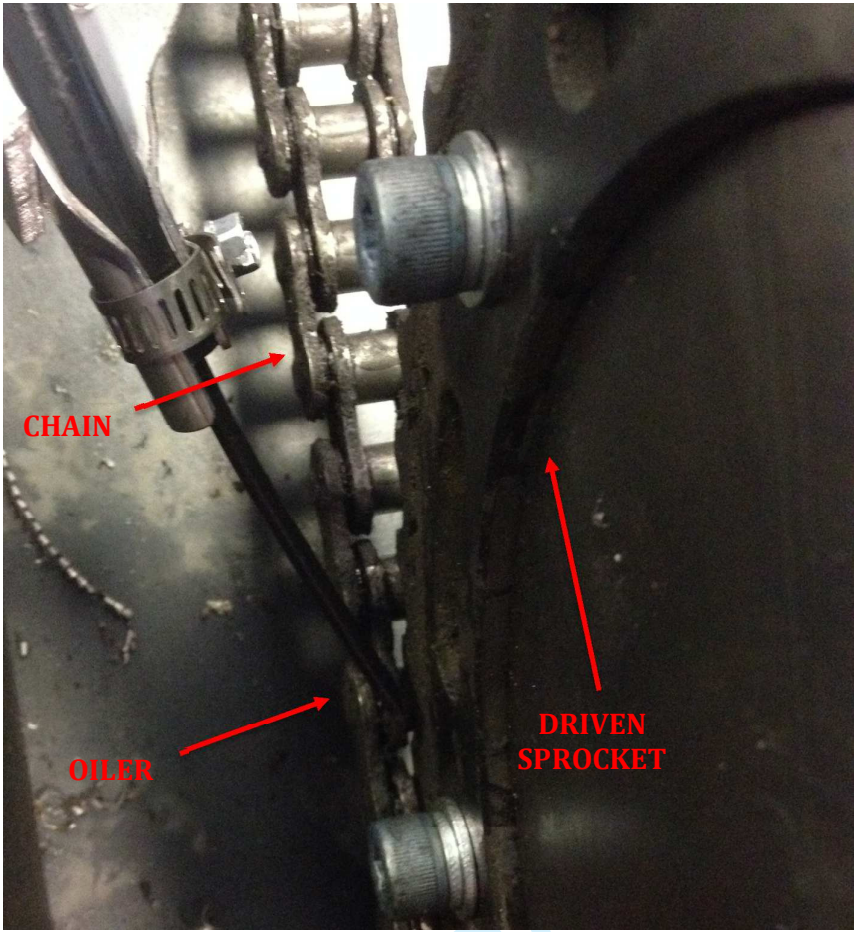
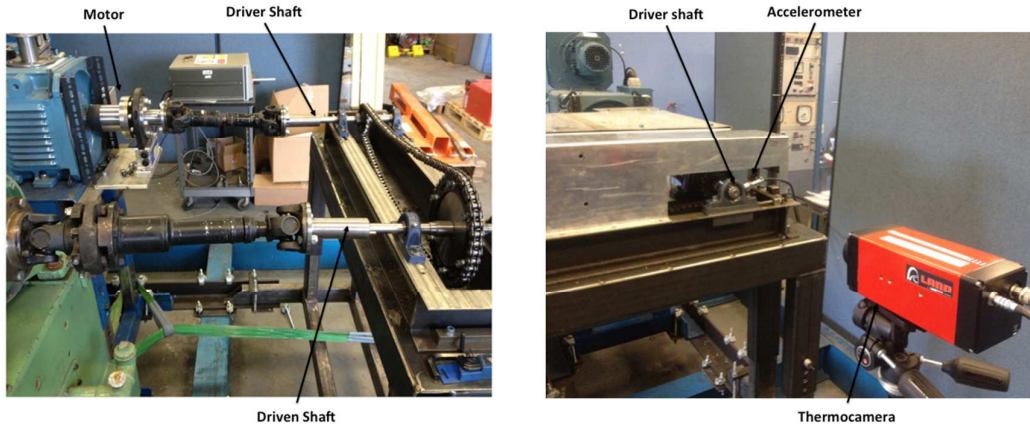


Figure 1: Automatic oiler and its position

Review



(a) Overall view of the rig

(b) Accelerometer and thermocamera

Figure 2: Experiment set up

For Peer Review

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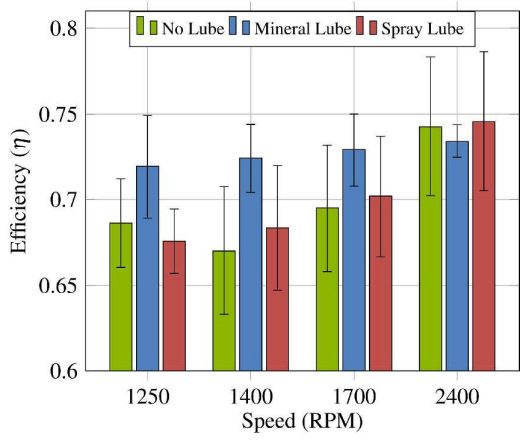


Figure 3: Mechanical efficiency of the transmission under different speed and lubricant conditions

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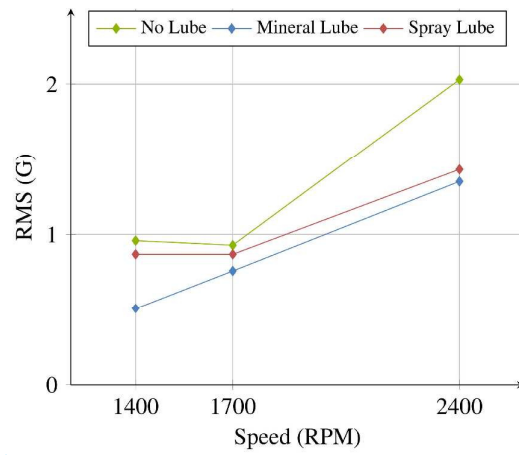
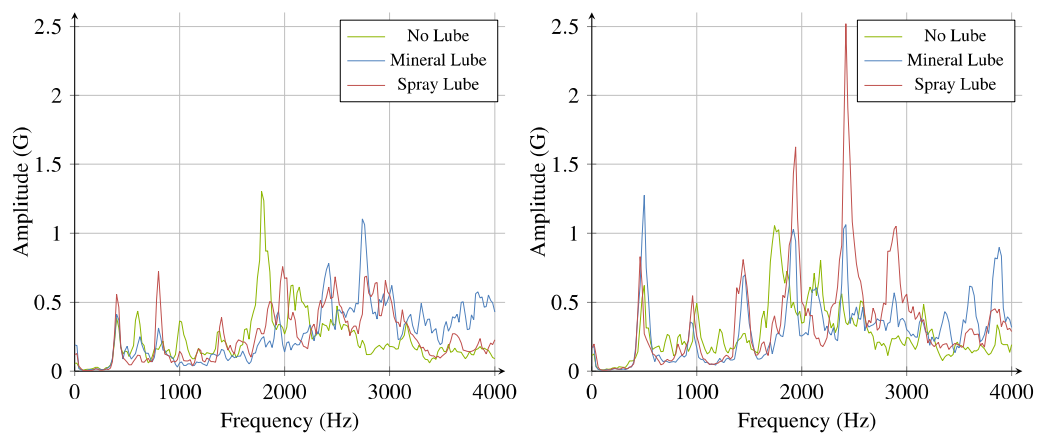


Figure 4: Root mean square

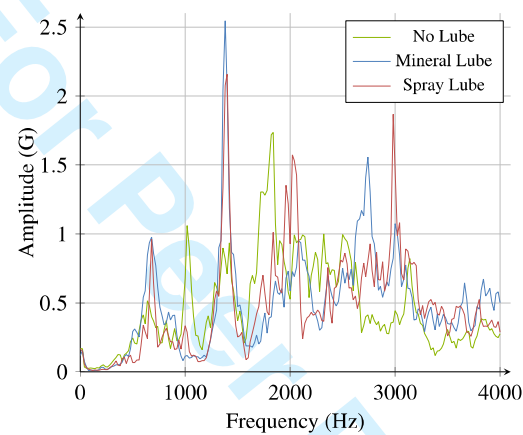
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(a) Frequency spectrum at 1400 RPM

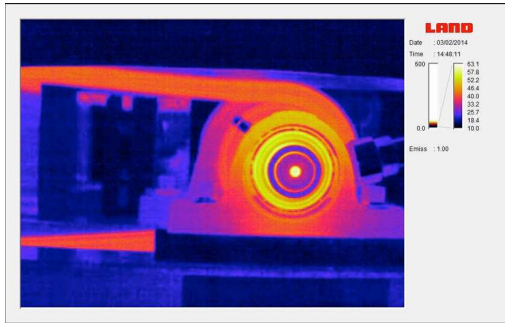
(b) Frequency spectrum at 1700 RPM



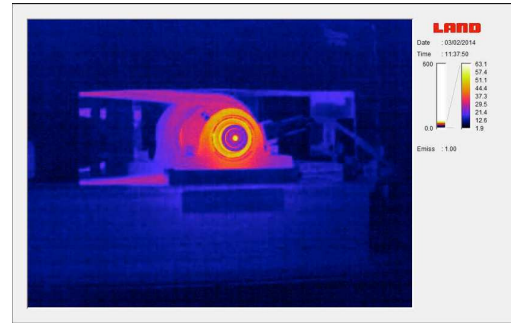
(c) Frequency spectrum at 2400 RPM

Figure 5: Frequency spectrum of the registered vibrations

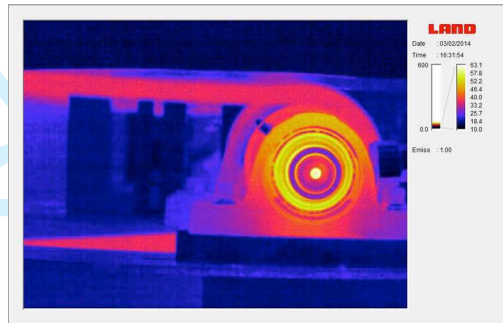
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(a) Thermo-Image of no lube condition



(b) Thermo image of mineral lube condition



(c) Thermo image of spray lube condition

Figure 6: Examples of thermo-images taken at 2400 RPM

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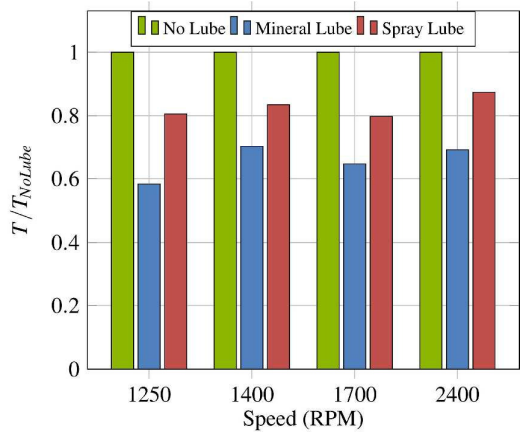


Figure 7: Chain temperature under different lubricant conditions

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Speed (RPM)	Efficiency (η)				
	No Lube	Mineral Lube	Gain (%)	Spray Lube	Gain (%)
1250	0.686	0.719	+4.81	0.676	-1.53
1400	0.670	0.724	+8.06	0.683	+1.99
1700	0.695	0.729	+4.88	0.702	+1.00
2400	0.743	0.734	-1.15	0.746	+0.40

Table 1: Mechanical Efficiency of Transmission

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Speed (RPM)	Root Mean Square (RMS)				
	No Lube	Mineral Lube	Gain (%)	Spray Lube	Gain (%)
1400	0.96	0.50	-47.9	0.87	-9.4
1700	0.93	0.76	-18.3	0.87	-6.5
2400	2.03	1.35	-35.5	1.43	-29.6

Table 2: Root Mean Square

For Peer Review

Speed (RPM)	Temperatures (°C)				
	No Lube	Mineral Lube	Gain (%)	Spray Lube	Gain (%)
1250	36.15	21.08	-42	29.12	-19
1400	34.60	24.28	-30	28.90	-13
1700	38.17	24.65	-35	30.45	-20
2400	40.85	28.20	-31	35.70	-13

Table 3: Temperatures (°C)

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