Developing of an E–Bike Testing Station and Measuring of Efficiency of E–Bikes

Jaromir Konecny, Martin Pies, and Martin Latocha

***Abstract*—Quality check in industrial process is required in more and more fields. One of such field is electric bicycle. Electric bicycles become more popular for general public due comfortable and ecologic possibility to transport. Before the electric bike leaves the factory, it should be tested. This article proposes concept of testing station, which is available to test electric bikes.**

***Index Terms*—Electric bike, Distributed measurement, Microcontrollers, Power system measurements, Prototype system, Quality check.**

I. Introduction

NOWADAYS general people use bikes. The bikes are popular not only in Netherlands, but also in China or in USA as it is mentioned in [7] and [8]. Moreover the popularity of electric bicycles rapidly increases in Czech Republic [1] (in czech). This article proposes concept of testing station for electric bicycles [2]. The aim of testing station is provide the complete test after production. Request of tested bicycles is the chassis does not be opened during the test. Battery pack is not part of the E-bike. The main idea is to fix the E-bike in the testing station, then simulate standard using and print certification. The E-bike support is active while pedals are spinning only [5], [6]. The simple solution is to connect motor, which will rotate pedals and it will simulate normal operation. The powered wheel is connected to electronic brake which simulates load. During the test several quantities are measured. The E-bike testing station is able to measure pedal motor current, voltage and power. Similar concept is presented in paper [3], but the novelty of this solution is in comprehensive testing system, which allows to estimate a potential maximum load of bicycle's propulsive unit. The electronic brake is able to measure, load, distance, speed etc. Moreover the battery simulator is connected and it measure input current, voltage and power. It is possible to calculate total efficiency of the bike. The concept is shown in Fig. 1.

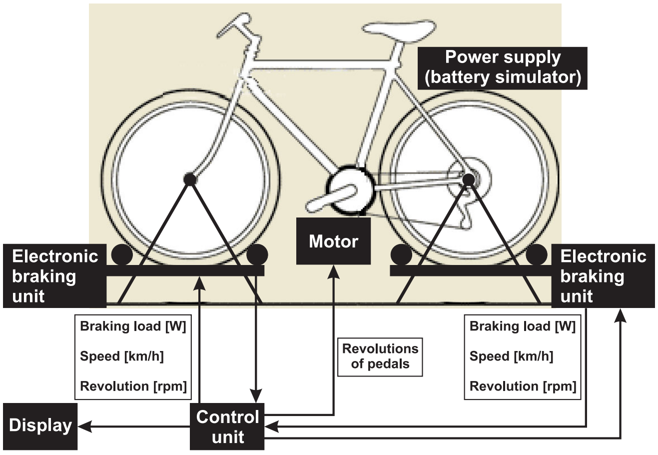

Fig. 1. Testing station concept

Fig. 2. E-bike testing stand

II. Hardware construction

E-bike testing station is constructed as modular system. Flexibility is one of the important properties. Hardware chassis is assembled from metal profiles and serves as stand. The tested E-bike is fixed into this stand. See Fig. 2.

The electric part is hidden in the cupboard and it includes the whole electric hardware. See Fig. 3. The heart of the stand is main module, which is connected to the computer via USB. Main module cares for timing, measuring and data collecting from electronic brakes and measuring modules. The electronic brakes are connected wireless via Nordic chip [9]. Moreover measuring modules can be connected to testing station. In this case one measuring module is connected. By connection another measuring module is possible to connect E-bike motor and measure its power. This functionality is not suitable for testing station, because it needs open the E-bike chassis and connect measuring module between E-bike motor and E-bike control unit. The E-bike motor and pedal motor need low voltage to operate. Two power sources MANSON are available in E-bike testing station [10]. This power sources can be controlled by the main module. The pedal motor revolution is controlled that way.

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III. Electronic construction

This chapter will describe E-bike testing station electronic. The concept was developed consideration modularity and flexibility. The E-bike testing station can be used as measuring station for design and developing. The heart of the E-bike testing station is main control unit designed on Freescale Kinetis K60 processor [11]. The tower system is used. The electronic is designed as elevator to Freescale tower system. The advantage is simple periphery construction. It is not necessary to take care for processor, because we are using tower development kit. The block diagram is shown in Fig. 3. The main control unit is powered by 12 V power source and it also provide power source to CAN bus. Two another power sources are used. The E-bike battery voltage is approximately 28 V, for this reason the regulated source MANSON $0-30$ V is used. For the purpose of spinning simulation the DC pedal motor is used. The motor voltage was chosen as the same as the voltage of measuring device. The pedal motor is powered by another regulated source MANSON $0-30$ V. The source is controllable by external signal. The external control signal is used for pedal motor speed regulation. The relay motor switching logic is used for quick stop and reverse spinning.

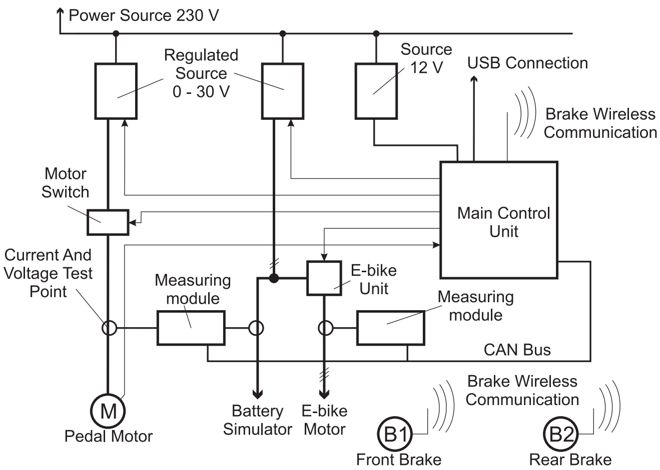

Fig. 3. E-bike testing station electronic block diagram

The E-bike control unit is also connected to Main Control unit. This feature allows to test motors separately. It also allows control support and it allows measure motor in entire range of use automatically. The main control unit is capable to connect with electronic brake. The E-bike testing stand includes two electronic brakes. The first brake can be connected to the front E-bike wheel and the second brake can be connected to the rear E-bike wheel. Whenever one of the electronic brakes starts rotate, it connects with main control unit and it starts sending measured data. The communication channel is wireless.

A. Measuring module

This chapter will shortly describe the concept of measuring modules. To preserve modularity and flexibility, the distributed concept was chosen. The main control unit provides CAN bus connection, moreover it provides power supply 12 V. Two measuring modules are connected to the CAN bus.

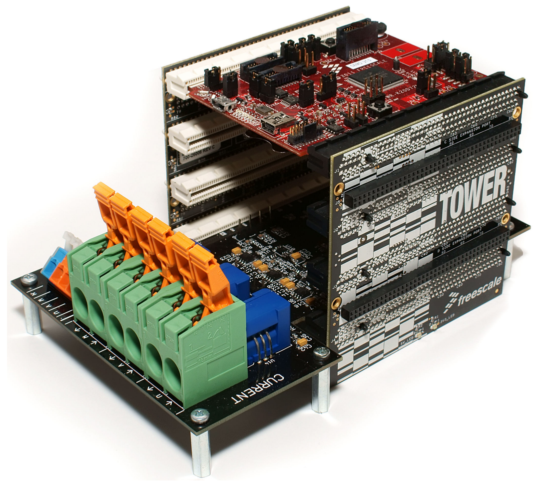

Fig. 4. Measuring module

Measuring module was designed as separate module based on Freescale processor K20, which is able to measure three phase motors. The E-bike control unit produces 16 kHz PWM modulated signal, so it is necessary to sample the data at least 32 kHz. The motor waveform shows Fig. 5. It shows three voltages phases and one current phase. The measuring module is capable to sample at frequency 100 kHz on three phases voltage and three phases current. Thus, total sample rate is 600 kSPS. The module has two AD converters and at same time is measured one current phase and one voltage phase. This provides to calculate power without time shift. In addition, the measuring module calculates power and total power in each step.

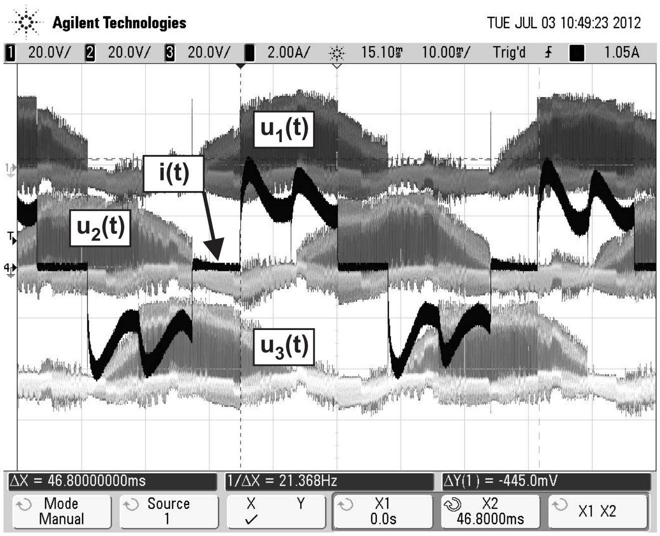

Fig. 5. Three voltage phase and one current phase

To measure AC power is important to detect period. The measuring module is able to detect periods from each voltage and current channel. See Fig. 5, period detection is much easier from current channel. To provide better functionality, the calibration is necessary. The calibration must be done directly in measuring module, because it calculates power in each step and then sum for one period. The power calculation shows equation (1).

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$$P = \frac{1}{N}\sum_{x=0}^{N} u_x \cdot i_x \qquad (1)$$

N number of samples during one period
u_x instantaneous voltage
i_x instantaneous current

The power calculation with calibration shows the equation (2).

$$P = \frac{1}{N}\sum_{x=0}^{N} (K_u u_x + Q_u) \cdot (K_i i_x + Q_i) \qquad (2)$$

where K_u, Q_u, K_i, Q_i are calibration constants.

Likely the computation capacity should be height. The direct memory access is used to decrease of computation power. One hundred samples are measured and then are processed. The processor should process 100 values in one millisecond. It should calibrate voltage and power, then calculate power, detect period, all for three phases and finally it should calculate total voltage, total current, total power and send it to the CAN bus. One value should be processed in less than 1.5 μs. It is clear, the computation power is high. The processor load reach up to 98 % during measurement.

To summarize the measuring module parameters:

- Measure three current phases −40 A to 40 A 100 kSPS each
- Measure three voltage phases −40 V to 40 V 100 kSPS each
- Calculate total 3 phase power
- Calibrate each sample (linear approximation is used)
- Provide DC measurement
- Provide AC measurement, trigger on each channel, up to 125 Hz
- Galvanic isolated power source and galvanic isolated CAN bus
- Fully isolated current channels
- Voltage channels with common ground

IV. E-BIKE TESTING

This chapter will shortly describe E-bike test procedure. One test involves several partial tests. The four basic tests are presented in this article.

1) Support test
2) Quick stop test
3) Reverse pedals spinning test
4) Load test

The first test should check the whole E-bike functionality. The pedal motor starts spinning and the support should start. The second test is quick stop test. The support should switch off in very short time maximum 280 ms after the pedal motor stop. After that test the pedal motor starts spinning in inverse direction. During this test the support should not start. The last test measure E-bikes total performance. E-bike is loaded by the brake and maximum power and efficiency is determined.

One of the issues is how to determine total power and total efficiency. The E-bike control unit has not constant efficiency for different speeds. The E-bike control unit has highest efficiency when the speed and support is maximal.

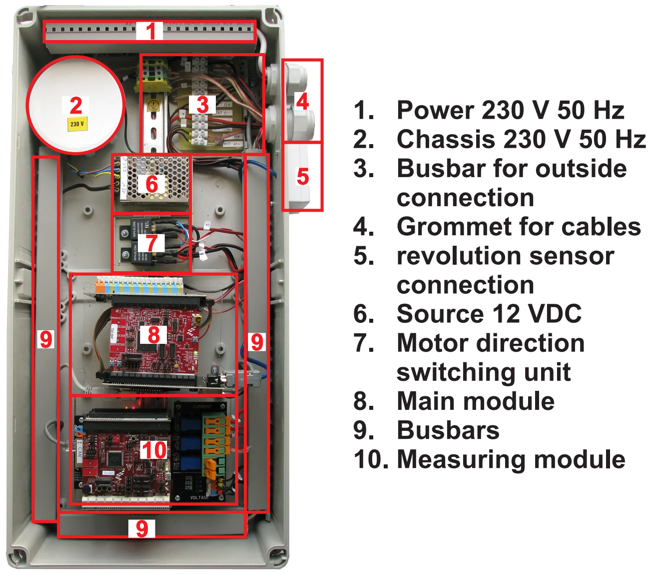

Fig. 6. E-bike testing stand electronic

Consider this situation. The E-bike support is maximal and the wheel speed is also maximal. The brake load starts increasing slowly. When the brake load reaches the maximum E-bike power, the speed drops and as a consequence the control unit efficiency also drops. When the efficiency drops, then maximum power also drops. As a result the speed falls rapidly. On the other side is electronic brake. The electronic brake load is also dependent on the speed. When the speed fall down, the load also fall down. The whole system stabilizes on certain state. Unfortunately this state not corresponds to efficiency and maximum power. The measurement of the maximum power and efficiency carries out closely to point, when the speed drops.

Another issue is transient response, when the load steps up. Following graphs was divided into three separated figures because of transparency. Fig. 7 shows efficiency, when the load step was 5 s. Fig. 8 shows efficiency, when load step was 10 s. Fig. 9 shows efficiency, when the load changed continuously. It is clear, the fluent load change suppress the transient response.

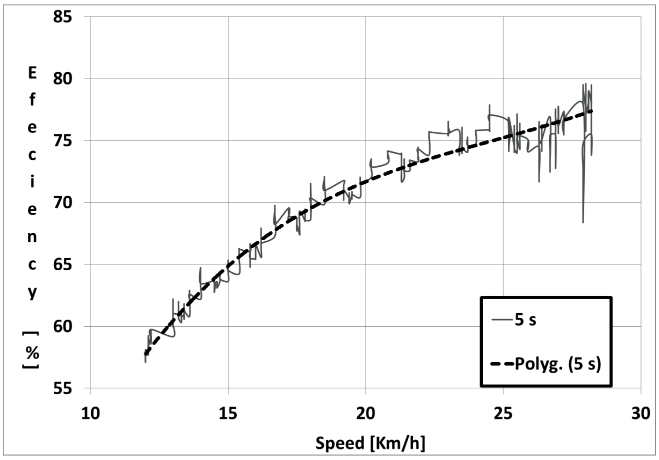

Fig. 7. E-bike efficiency test – 5 s

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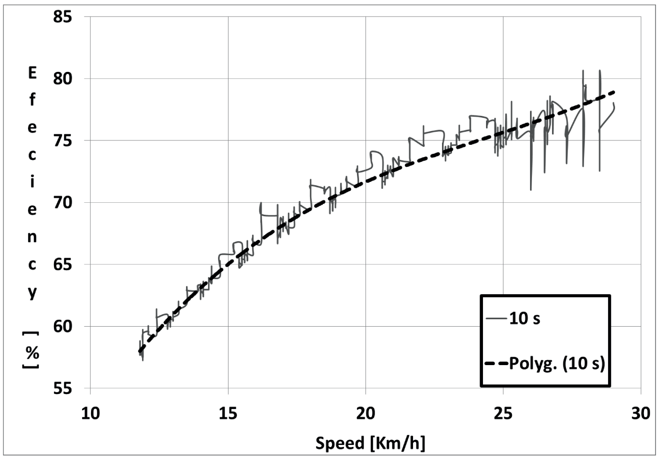

Fig. 8. E-bike efficiency test – 10 s

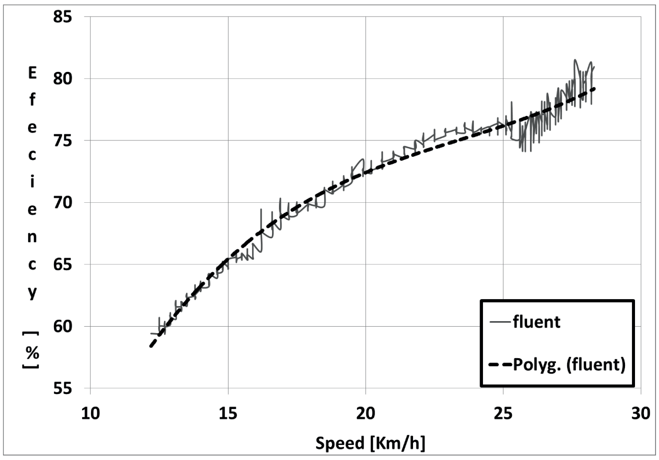

Fig. 9. E-bike efficiency test – fluent

V. Conclusion

This article presents E-bike testing station, which is capable to provide complete quality check and replace testing drive. The station is assembled in assembly line and it is used for quality check. One test takes approximately two or three minutes and it replaces test drives, which are subjective. The E-bike testing station is also able to provide sophisticate measurements. In addition, the E-bike testing station includes measurement module, which is able to measure three-phase power. The module sample frequency is 100 kHz. Moreover includes display test, battery test and any other test. E-bike testing stand provides complex measuring and testing station for quality check and research and development.

The E-bike testing station has several advantages. The first advantage is to make the quality check more objective instead of subjective testing drive. The second advantage is ability to print protocol and save measured data with barcode to the database. It provides valuables data for the developer and production. The next advantage is ability to reload particular test, when the costumer make complain. The disadvantage is price of the entire solution. The final cost was around 65.000 $. This cost involves expenses for hardware chassis, electronic, fully modular C# testing application and research expenses. For the future work we are expecting process the measured data. We expect, we will make data analysis and try to find some innovative way to increase the E-bike quality. For example we will try to analyze the efficiency of different E-bike constructions, different E-bike control units and motors. The E-bikes can be also fitted up by GPS tracking system, as it is shown in [4].

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