Braking can be one of the causes of damage or a complete destruction of a controller. This kind of controller destruction is not as obvious as for example battery reverse polarity, and thus it is necessary to explain it in more detail. If you get familiar with the braking mechanism, it will be easier to prevent problems. Controller's „survival" of braking depends on numerous factors. To start with, it is the used motor, revolutions, model (its weight), gearing, quality and condition of a feeding battery and also of conductors and connectors. Intensity of braking is also very significant. These are all conditions that can be hardly affected by the controller.

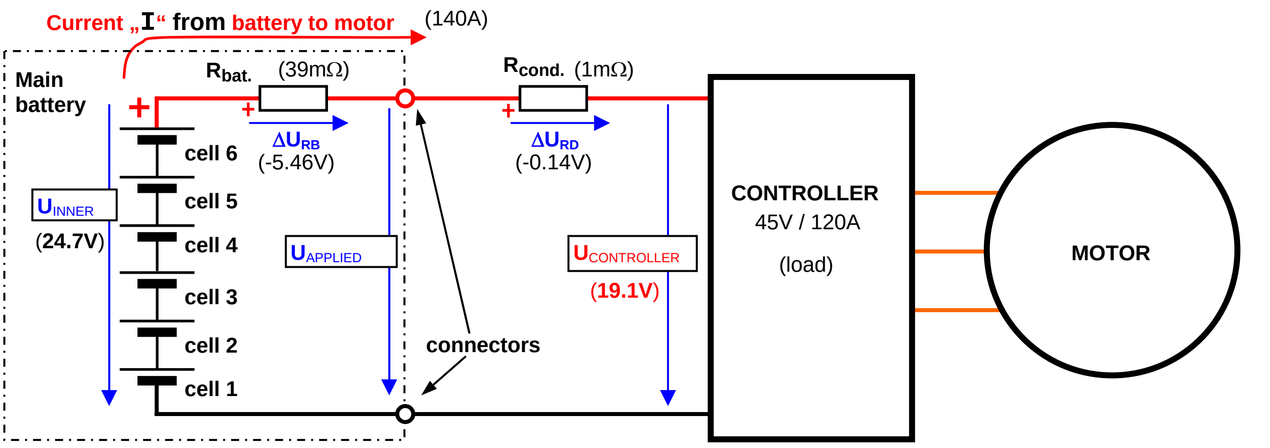
Batteries used in the following tests were:
a) Kokam K5000/30C/6s
b) K4800/20C/6s
c) another 5Ah battery, not very quality

and used motors were -
a) ACS 18/20-100 MP JET
b) NEU 1521/1D/F

Controller used for the tests was an older type of TMM12032-3 (120A, 45V). A simplified scheme of the feeding set of the controller may be found in the two following figures. For clarity, concrete values of voltages, currents and resistances are shown (short conductors, very small inner resistances of battery, medium braking currents).

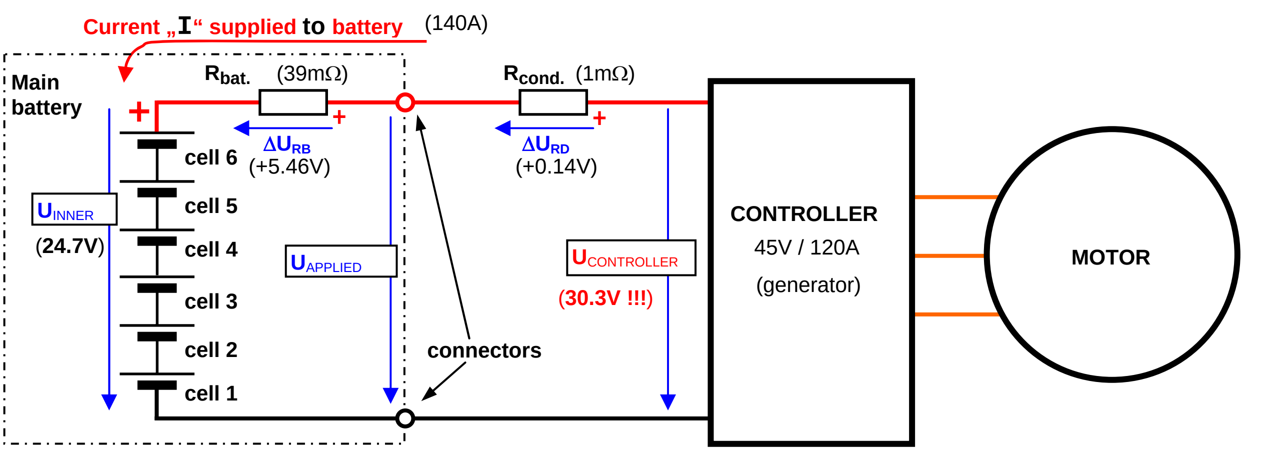
In fig. 1, situations during operation when motor draws currents from the feeding battery, that is start up and ride, is shown. In such situations, the current is drawn from the battery with voltage (U_{INNER}) to the controller. Current flow through inner resistances of the battery and other resistances ($R_{battery}$ + $R_{conductor}$) in a circuit (conductors, connectors) causes loss of voltage on these resistances so that the voltage on the input of the controller is lowered by these voltages. The higher the flowing currents (**I**) and the higher these resistances, the higher voltage is caught on them and the less voltage will be on the input to the controller ($U_{CONTROLLER}$). $U_{APPLIED}$ voltage can be measured on the clips of the battery.
If the drawn current is too high or the resistances too big, the voltage for the controller may drop to too low voltages, with which the controller may not work correctly, and this situation at the same time damages the controller.

Fig. 1 - situations during ride: (controller with the motor consumption energy from the battery)

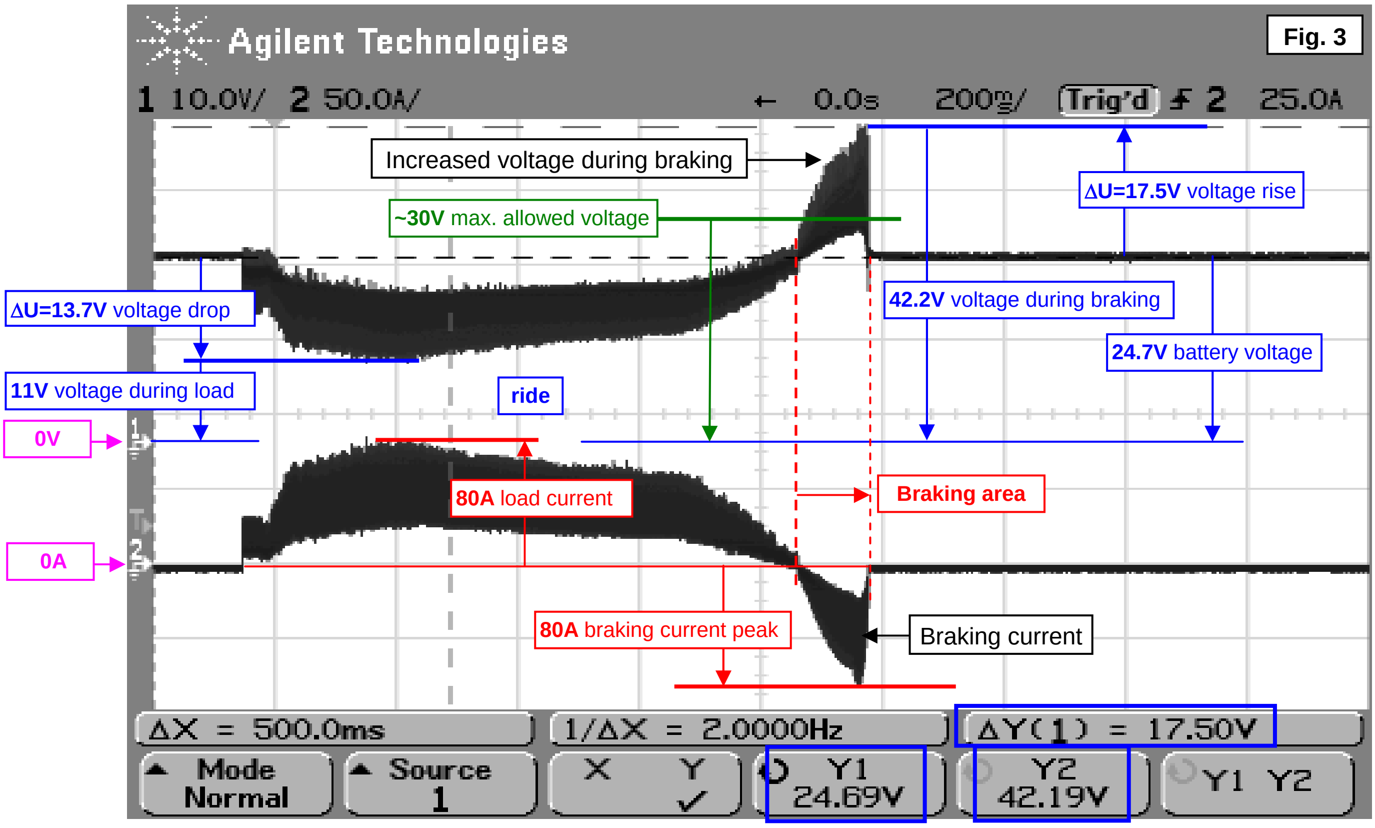


Quite different situation occurs during braking (Fig. 2). In such case, motor together with the controller behaves as a generator and currents flow to the battery. Again, resistances in the circuit have to be accounted for (inner resistances of the battery, as well as resistances of conductors, connectors, etc). Because the direction of the current flow is now opposite, also voltages caught on resistances in the circuit have opposite polarity and **they are thus added** to the voltage of the battery. This causes increase of voltage on the input of the controller during braking. If this voltage is significantly higher than maximal values given by components used, the controller may be easily damaged – seemingly without any reason.

Fig. 2 - situations during braking: (controller with the motor supply energy to the battery)

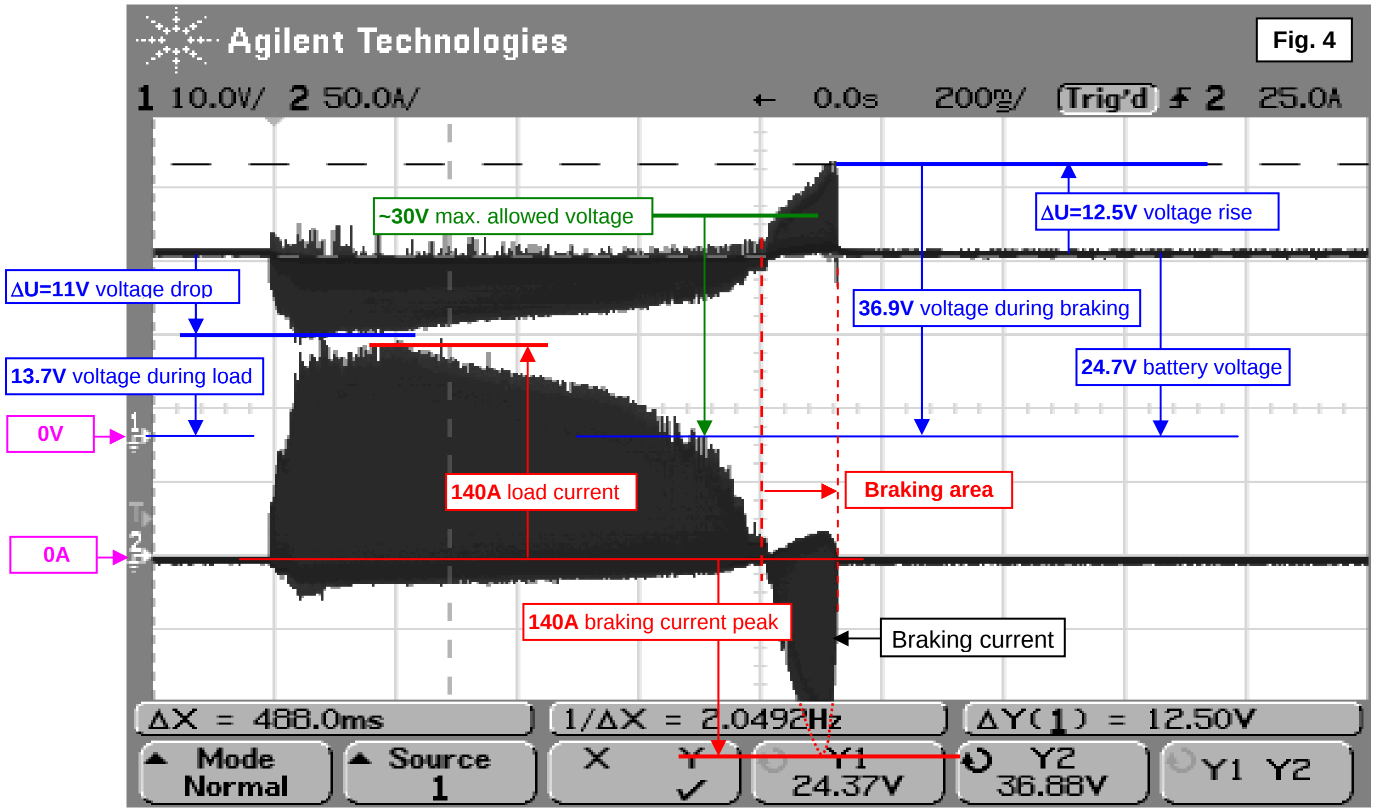


Lipol battery made of two average quality 3S packs (therefore 6S pack), conductor between the packs is 32cm (12.6 inches), conductor from the battery is also 32cm (12.6 inches), connectors to the controller 12+12cm (4.7 + 4.7 inches), cross-section is 2.5 and 4 mm^2 (~13 gauge and ~11 gauge), resistance of the conductors themselves is ca 4mΩ. The 4 connectors have a total resistance of ca 1mΩ. This battery with conductors and connectors have a total resistance of 170mΩ. Situation in the feeding circuit is shown in figure 3.



The situation is critical; we can see that voltage peaks on the input to the controller are up to 42V during braking. If a controller for 6 Lipols, which can hold up to 30V, was used, it would have been completely destroyed even during first such braking. (Increase in voltage is 17.5V!!! with a relatively small braking current, in the order of only ca 80A).

If a better battery is used (with a total inner resistance of ca 80mΩ), with shorter conductors, the situation is better, however still not satisfactory. Voltage will increase „only“ by 12.5V to ca 37V when braking with almost double the current (140A). This however, a controller for 6 Lipols usually does not survive. Needless to say, that if we would not brake or brake softer, it would work without problems. The situation is shown in fig. 4.



In both cases, it is therefore enough to intensively brake only once and the controller can be easily and quickly damaged, basically after few meters' ride.

The paradox is that the better controller you use (the more quality FETs and PCBs, or the more FETs and thicker copper layers it has on pcbs, that is smaller resistances of FETs and connections it has), the worse the situation. The motor, working as a generator during braking, causes more energy (current) to flow to the battery. Thus higher voltages are caught on the resistances of the conductors (Rconductor) and inner resistance of the battery (Rbattery) and therefore higher voltage will also be on the input of the controller ($U_{CONTROLLER}$). That means, the destruction of the controller is more likely to occur when there is not enough reserve in its voltage dimensioning.

How to solve this situation? There are three, resp. four ways.

a) Use batteries that **have truly** very small inner resistances (as e.g. Kokam 30C with a suitable capacity).
It is therefore not enough that the seller or distributor states „high Cs" for the battery and that it can supply high currents!!! An example of such batteries are packs made of A123 cells, which can provide high currents without damaging themselves, but the inner resistances are high. At the same time, it is necessary to make sure that conductors between the battery and the controller are as short as possible and use quality connectors, that is no "4 mm golden plated banana plugs" or "Dean" etc., but at least MP JET 3.5mm or better 5.5 or 6.0mm. Conductors with a cross-section of at least $4mm^2$ are also essential (that is 11 gauge in US units) and quality soldering (our concern are not 1:18 models, but the bigger ones, of course).
Nevertheless, even batteries with very small resistance might not be enough – in some combinations with powerful motors and bigger models, even with a very good battery, voltages higher than the controller can take can be generated.

b) Use **controller for higher voltage** than it seems to be needed from the point of voltage on the pins of the battery (that is for 6Lipols use controller suited for at least 8 Lipols).

c) Use „controlled shunt load" for partial braking current stream diversion, additional module for controllers – under development.

d) Brake softly – this however is quite hard to achieve correctly in practice.

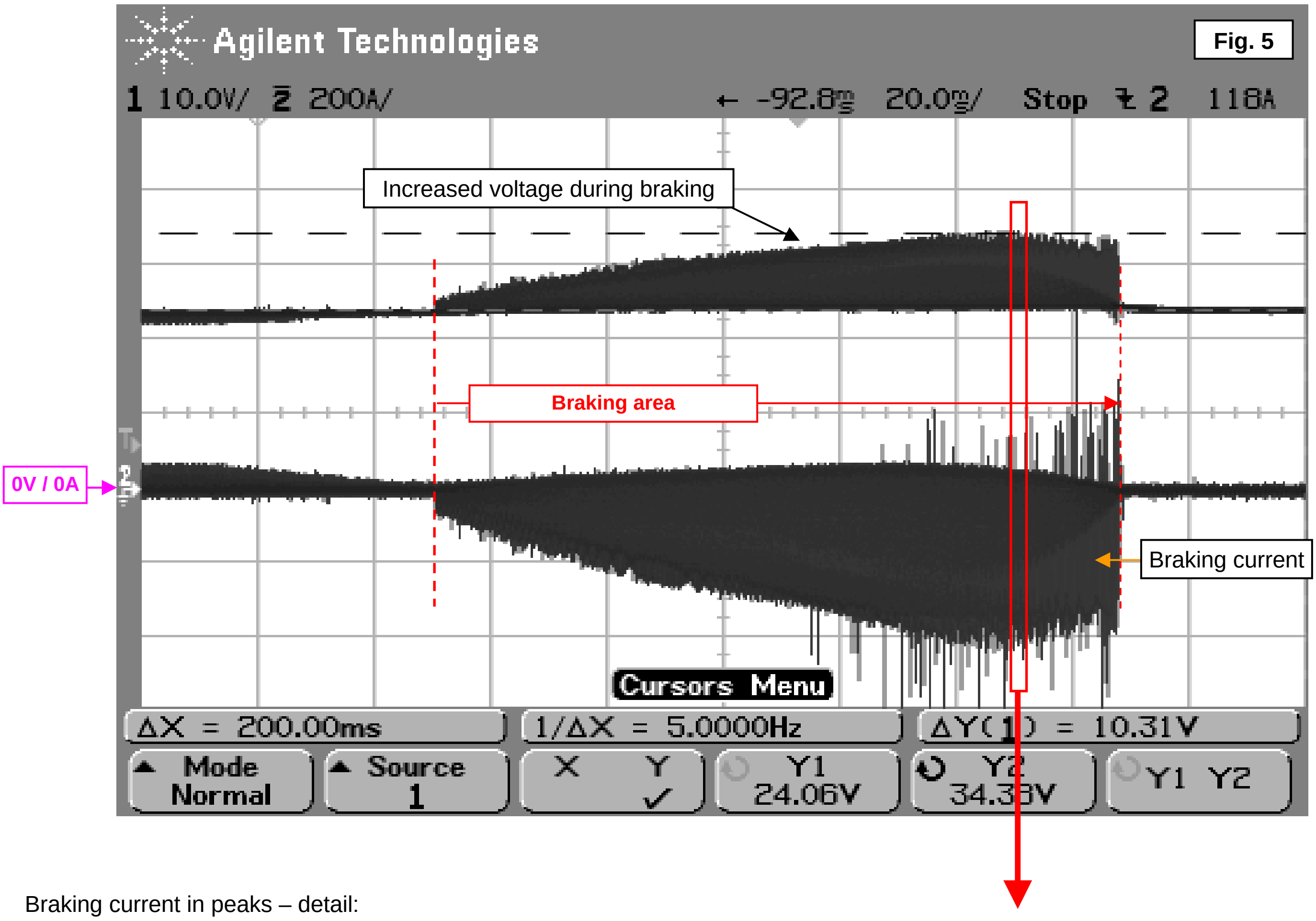
Most likely **b)** is the safest method, but method a) is also enough in a lot of cases. Measuring the real situation in the model is rather difficult in home conditions, so if you work with limit number of cells (that is 5 and 6 cells for 6Lipol controllers), it is safer to combine approaches **a)** and **b)**, that is to use controller for higher voltages and the best packs at the same time, respectively combination of **a)** and **c)** if never mind additional module (dimensions and weight).

Notes to conductors:

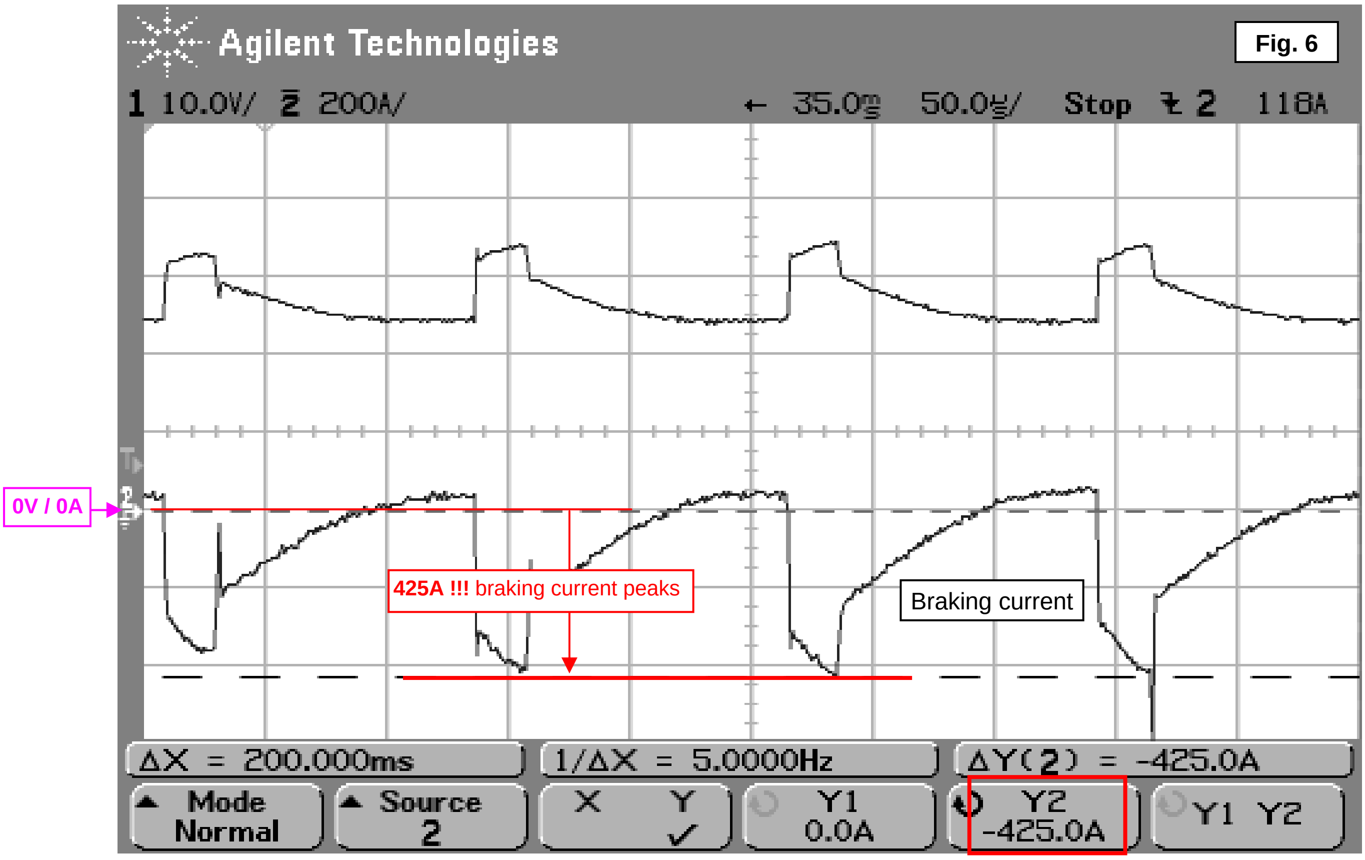
Please note that for conductors with a cross-section of $4mm^2$ and a total length of 20 cm (7.9 inches) that is 5 + 5cm (1.96 inches) for the battery and 5 + 5cm for the controller), so with a resistance of 1mΩ, and current of 140A, a loss of 19W is generated. If you do not take care of the length of the conductors and let them be e.g. 60 cm (23.6 inches) (that is for example 10 + 10cm (3.9 +3.9 inches) for the controller and 30+10 cm for the battery (11.8 + 3.9 inches), the loss on these conductors with the same current will be ca 57W. This power causes the conductors to warm up. It is similar to connecting a 60W bulb.
Even bigger problem than the resistance of conductors can be caused by inductance of long conductors, which raises the resistance of the conductor for AC processes and makes the whole situation even worse. This is why an additional filtering capacitors (always „very low ESR", 105°C) between controller and battery (as close to the controller as possible) are recommended when longer conductors are used.

Other examples of braking:

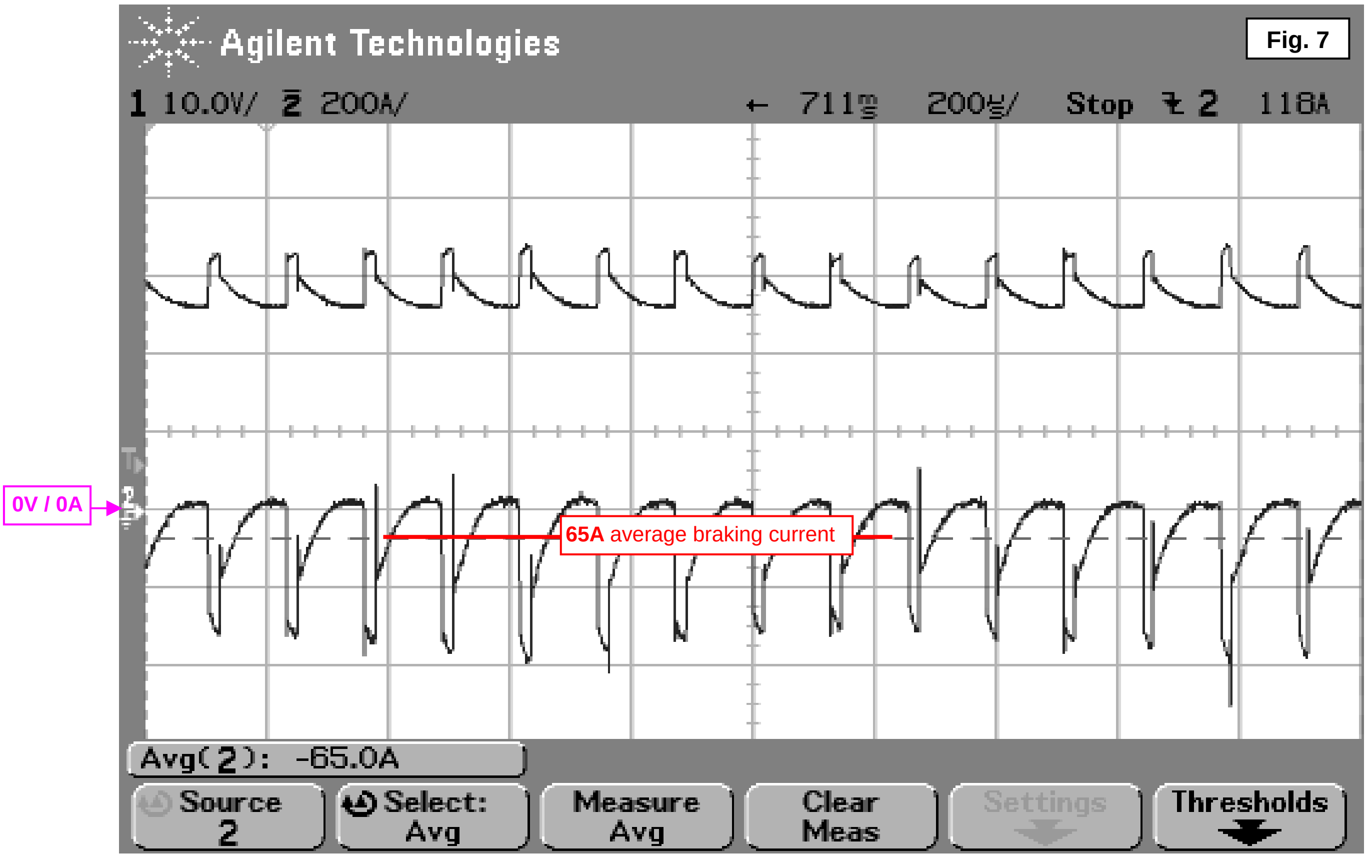
Motor Neu 1521/1D, battery K5000/30C, 6s



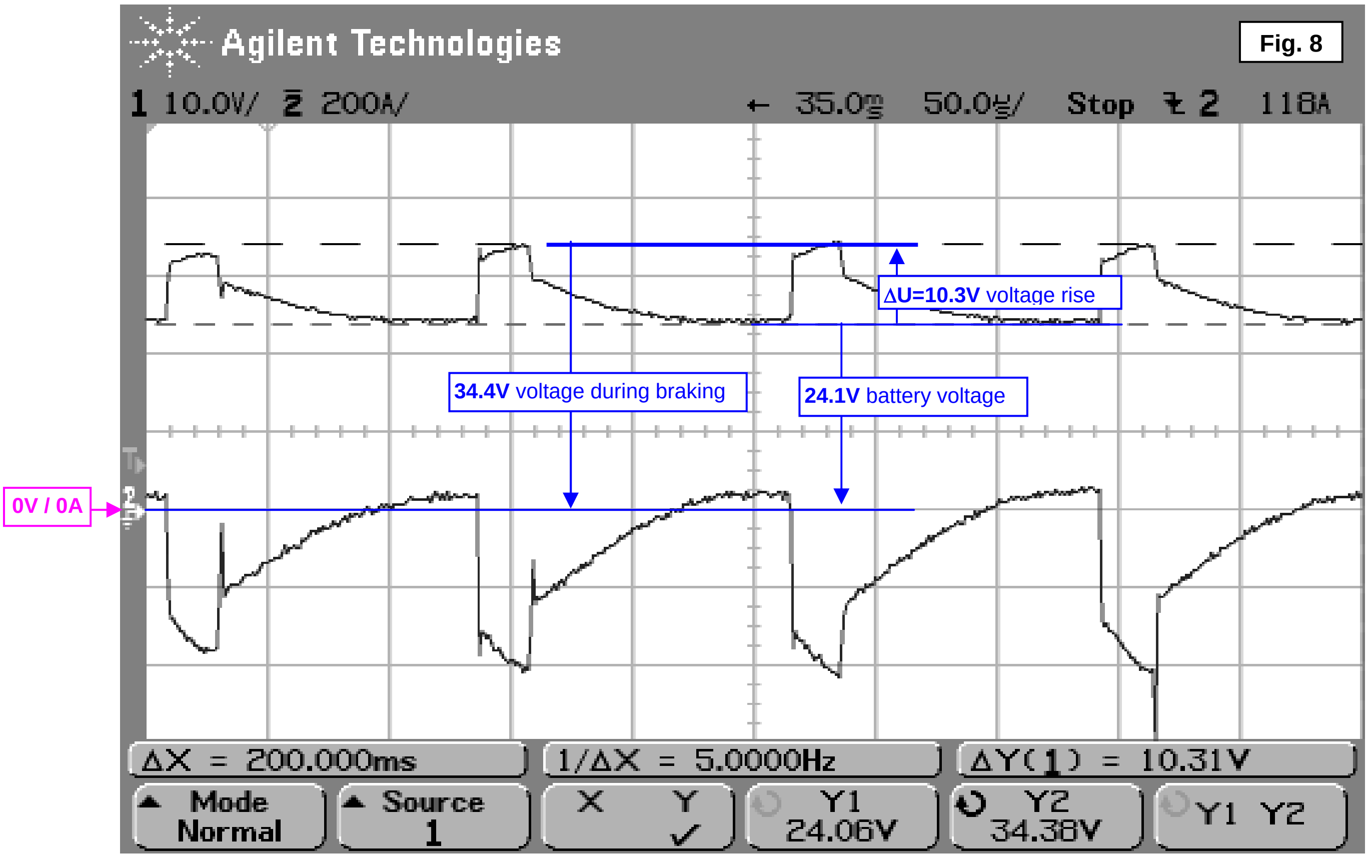
Braking current in peaks – detail:



Average braking current:

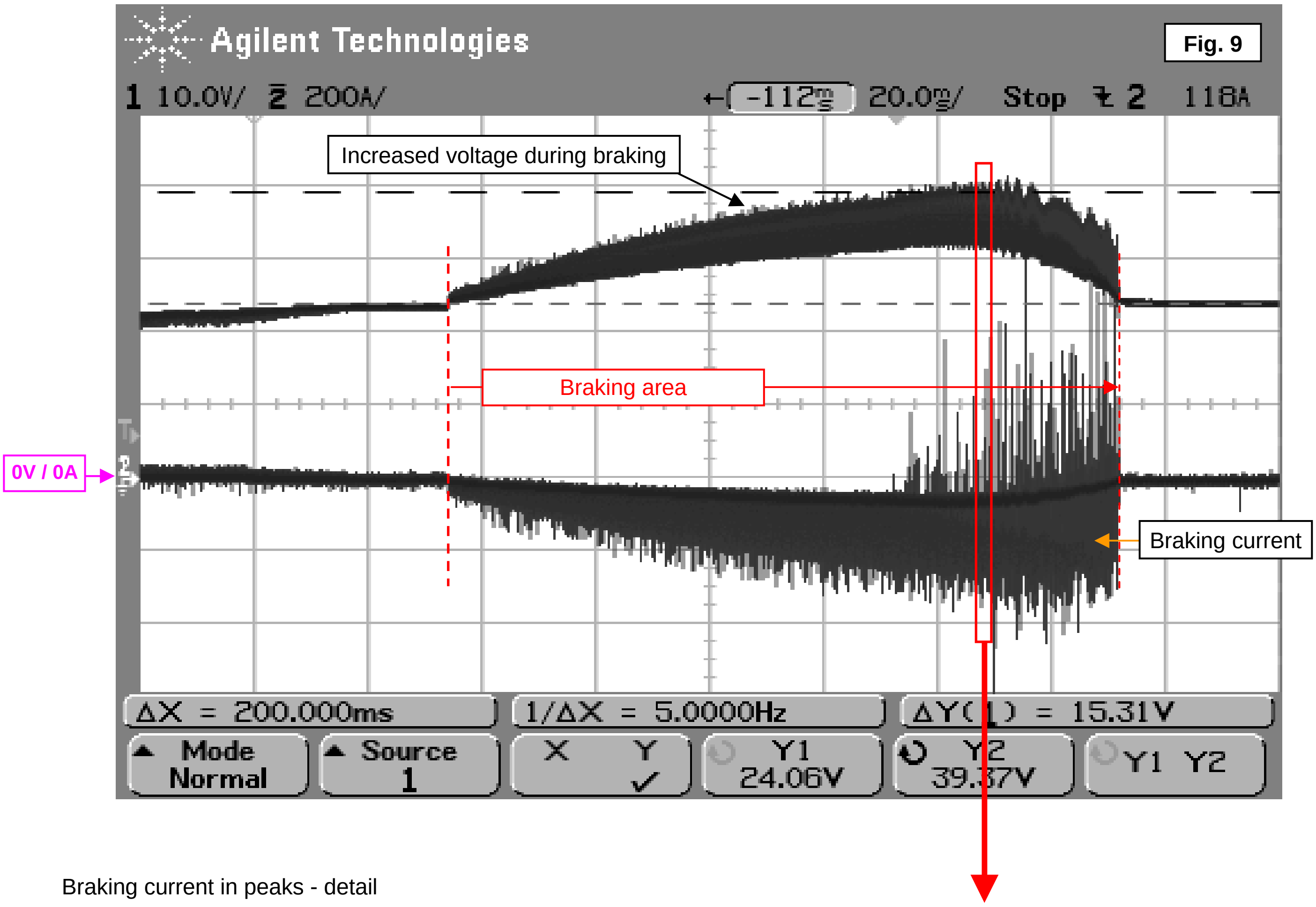


Voltage during braking - detail:

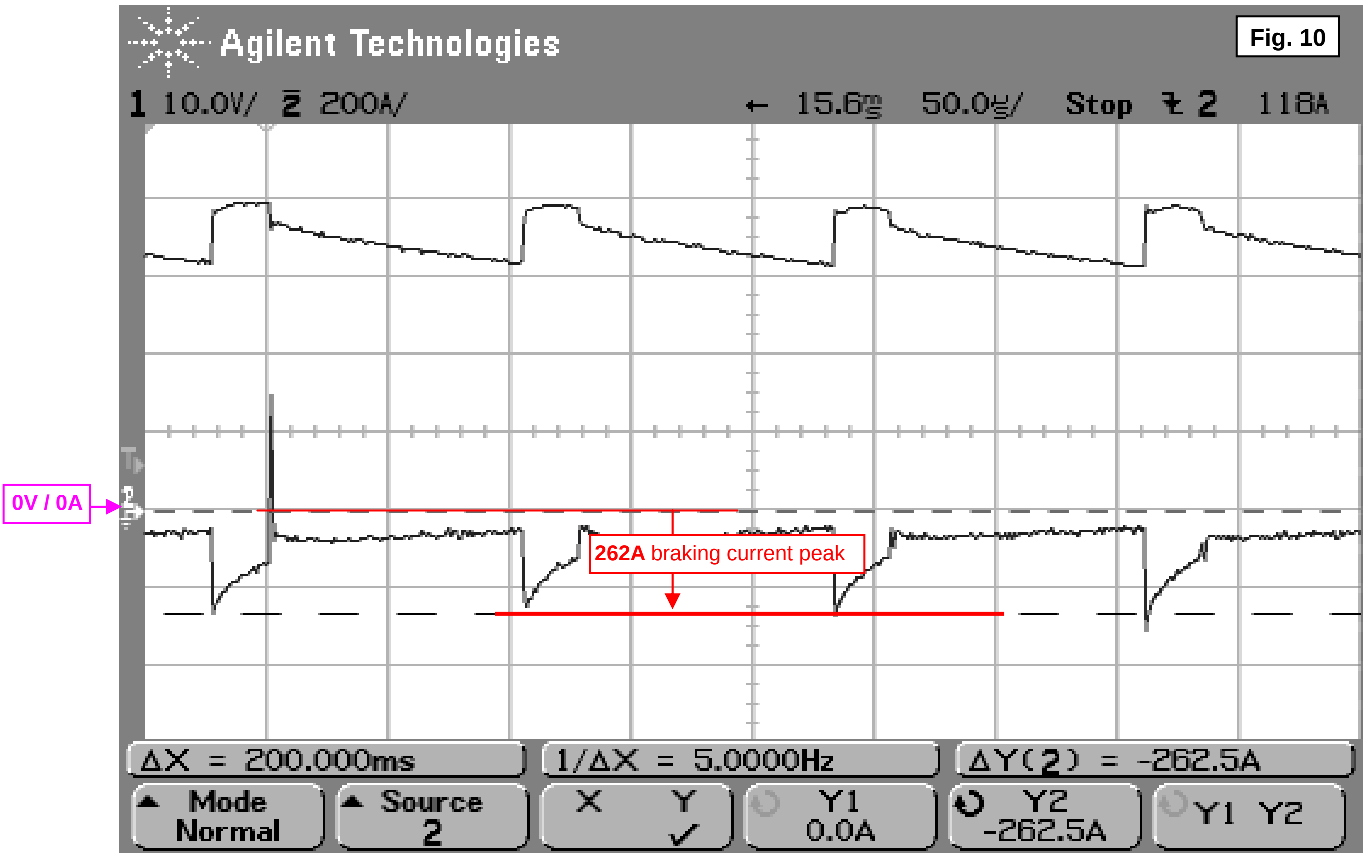


It is obvious that when a powerful motor is used together with fast braking, controller for 6 Lipol cells would be significantly endangered even with very good batteries (voltage of 34.4V in peaks). One way to solve this would be to use a 6S/2P pack to lower the inner resistances or again better use a controller for higher voltage (for 8 Lipols), or the combination of both.

Motor Neu 1521/1D, Lipol „noname“ 5000 mAh, 6s in fig. 9 (not the best one)



Braking current in peaks - detail



Voltage during braking - detail.

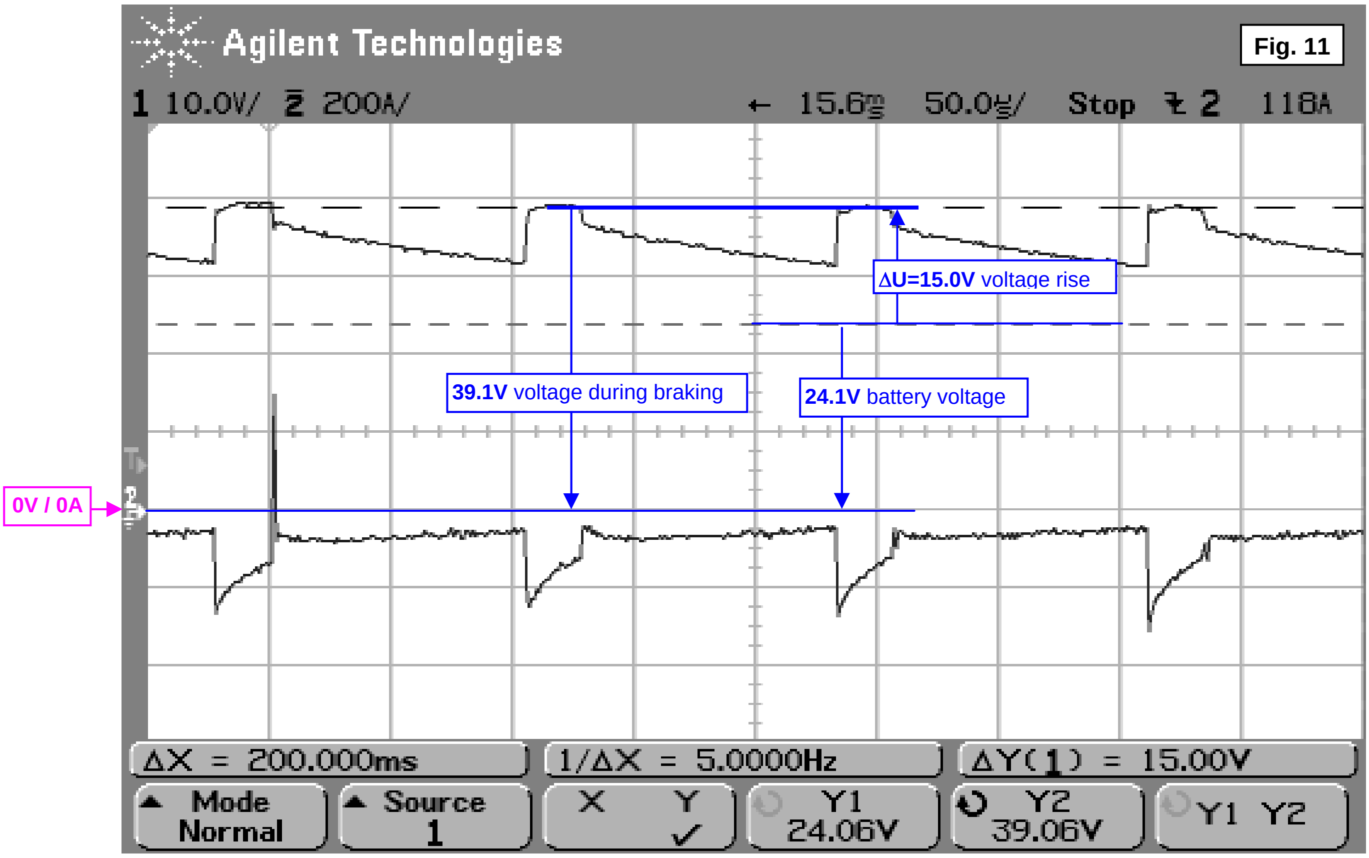


Fig. 11

This battery cannot be used with the given motor.
Voltage on the controller rises by 15V (to 39V) during braking. This would certainly lead to a destruction of a controller for 6 Lipol cells (max. feeding voltage is 25.5V, max. voltage on input ca 30V), controller for 8 Lipol cells would be on its limits.

After connecting two BZW50-22 TRANSILs parallels to the controller (that is 2x5000W and current in pulses 2x127A, reps. up to 1177A) and braking, both TRANSILs burnt (one literally bursted), both were short-circuited, this was followed by unsoldering of a conductor from the battery due to extreme current causing overheating - thanks to that the battery was saved), the controller did, thanks to short-circuiting of the TRANSILs and thus the voltage on input, survive.
Obviously, protective parts like this cannot be used to suppress voltage peaks during braking.

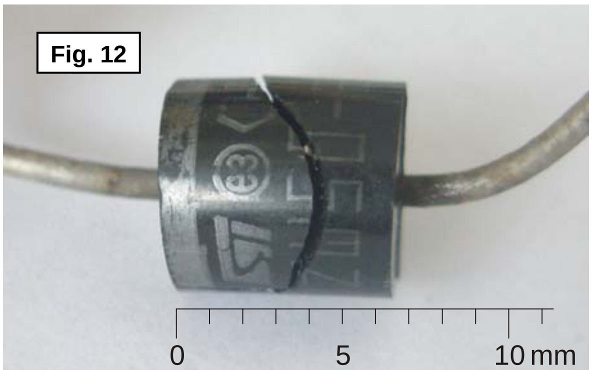


Fig. 12

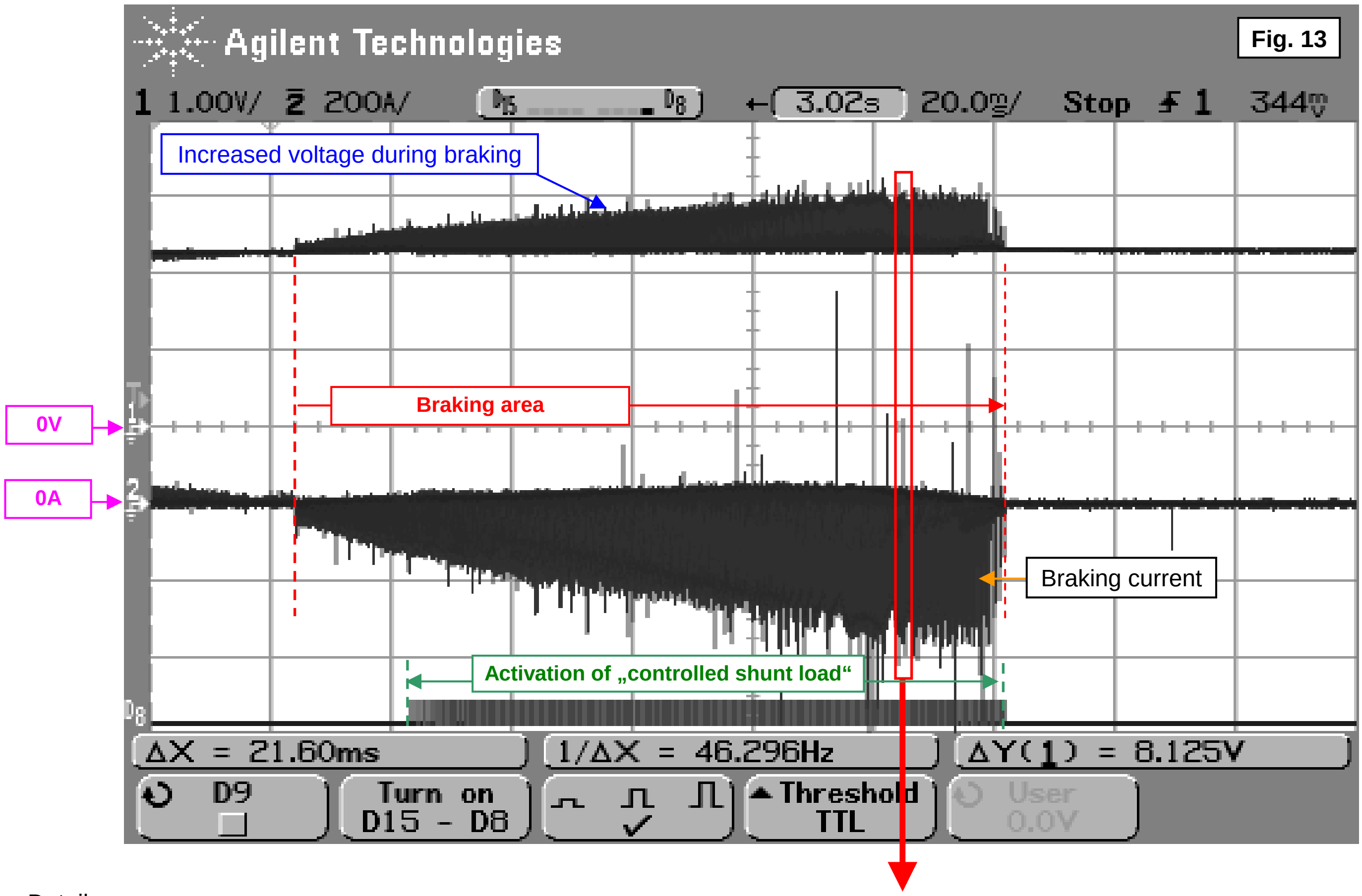
Situation analysis:
It is not possible to use parts like TRANSIL in order to easily reduce voltage peaks generated during braking, when an unsuitable battery is used – energy in the process is too big.

It is thus necessary to use batteries with very small inner resistance, the shortest and widest conductors, quality and well dimensioned connectors and also to over dimension the controller regarding voltage, especially when it is expected to work near its voltage limits (eg. using 5 or 6 Lipols for 6Lipol controllers).

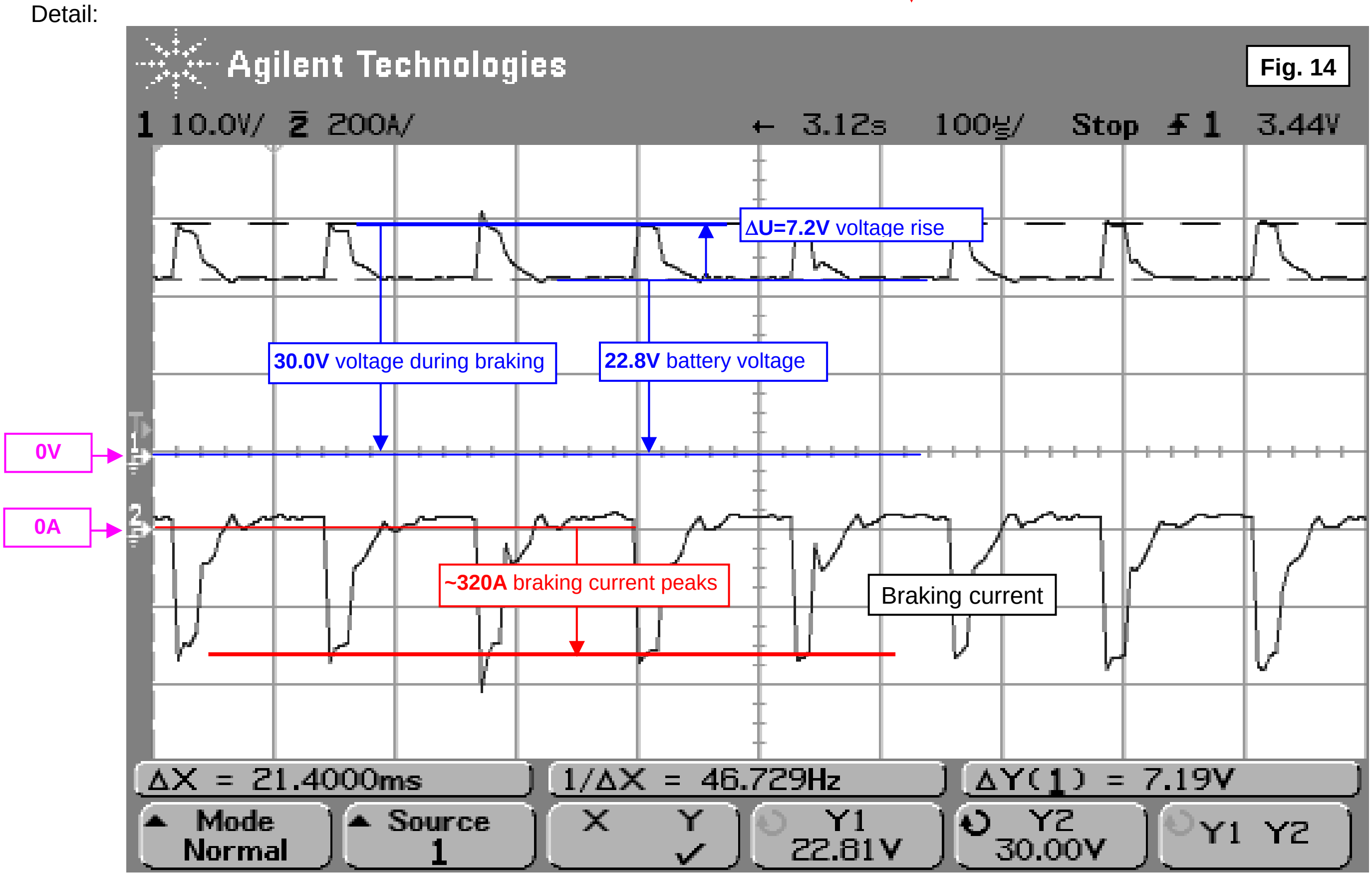
The explained phenomena's during braking are based on physical principals and the controller cannot affect them significantly (maybe except for the intensity of braking), therefore it is necessary to respect them and dimension the controller itself as well as its surrounding parts accordingly.

Next possibility is using of the "controlled shunt load" - point c). See next page for result.

Motor Neu 1521/1D, battery K5000/30C, 6s, controller with additional module „controlled shunt load".



Detail:



This is the same situation as in figure 5 and 6.
Braking currents decrease from 425A (fig. 5 and6) to ca 320A. Voltage rising decrease from 10.3V to 7.2V. Additional module is set for 30V max., current through module ca 100A. Now is working on the 200A module.

Appendix:

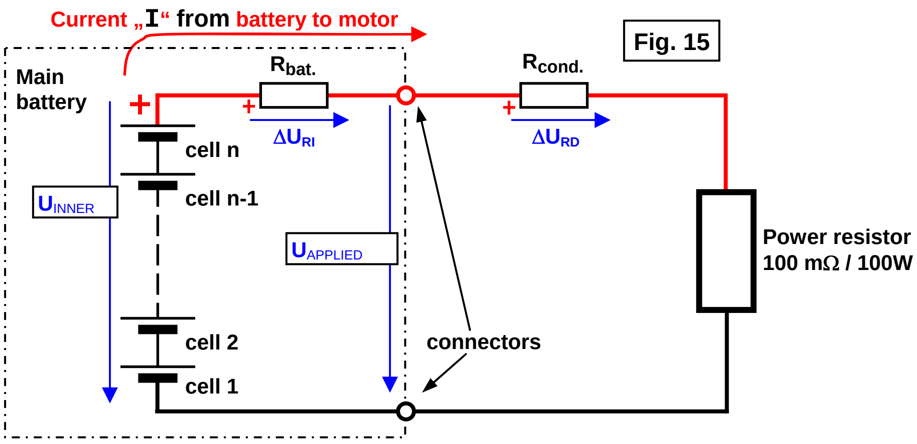
To get at least a general idea about features of your battery, you may do a simple measurement of the inner resistance even in home conditions (even though you will get a slightly different result than that given by the producer, if however any value is given). The resistances of conductors and connectors are omitted.

1) measure the voltage of the battery on its outputs (pins), without load - you are measuring U_{INNER}
2) connect a power resistor to the pins of the battery and again measure the voltage on the pins ($U_{APPLIED}$) and at the same time the current flowing from the battery. Work swiftly, the resistor will warm up quickly - it is very overloaded. Few seconds are usually enough to do the measurement.
3) calculate the inner resistance of your battery:

$$R_{bat.} = (U_{INNER} - U_{APPLIED}) / I$$

For example, when a 100mΩ resistor is used, currents will be (depending on the inner resistance of the battery) in order of 80 to 150A for 6 Lipol cells. This is enough for most measurements. Such resistor can be easily realized by connecting 10 pcs of 1Ω/10W resistors in parallel which can be obtained from a store supplying electrical components.

It is best to measure the current with a clamp ampermeter; voltage can be measured with any regular voltmeter.



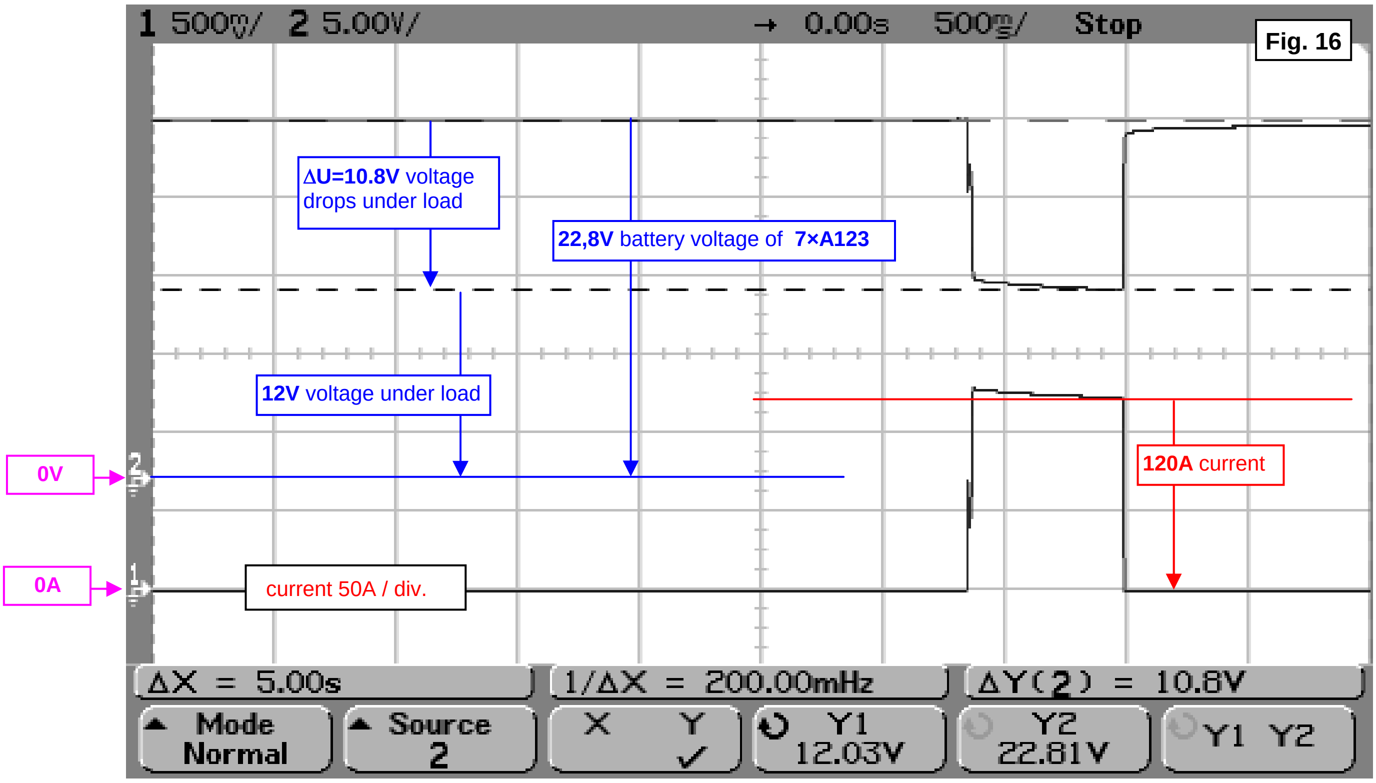
Inner resistance of battery does not describe the battery behavior completely during short charging pulses, but it can serve as a good lead for comparing different batteries. Most likely „chemical reactions“ of the cells in microsecond charging pulses play a role here. Another distorting part are filtering capacitors on the inputs of the controller, which do absorb a part of the energy during braking current pulses.

Rbat. = inner battery resistance.

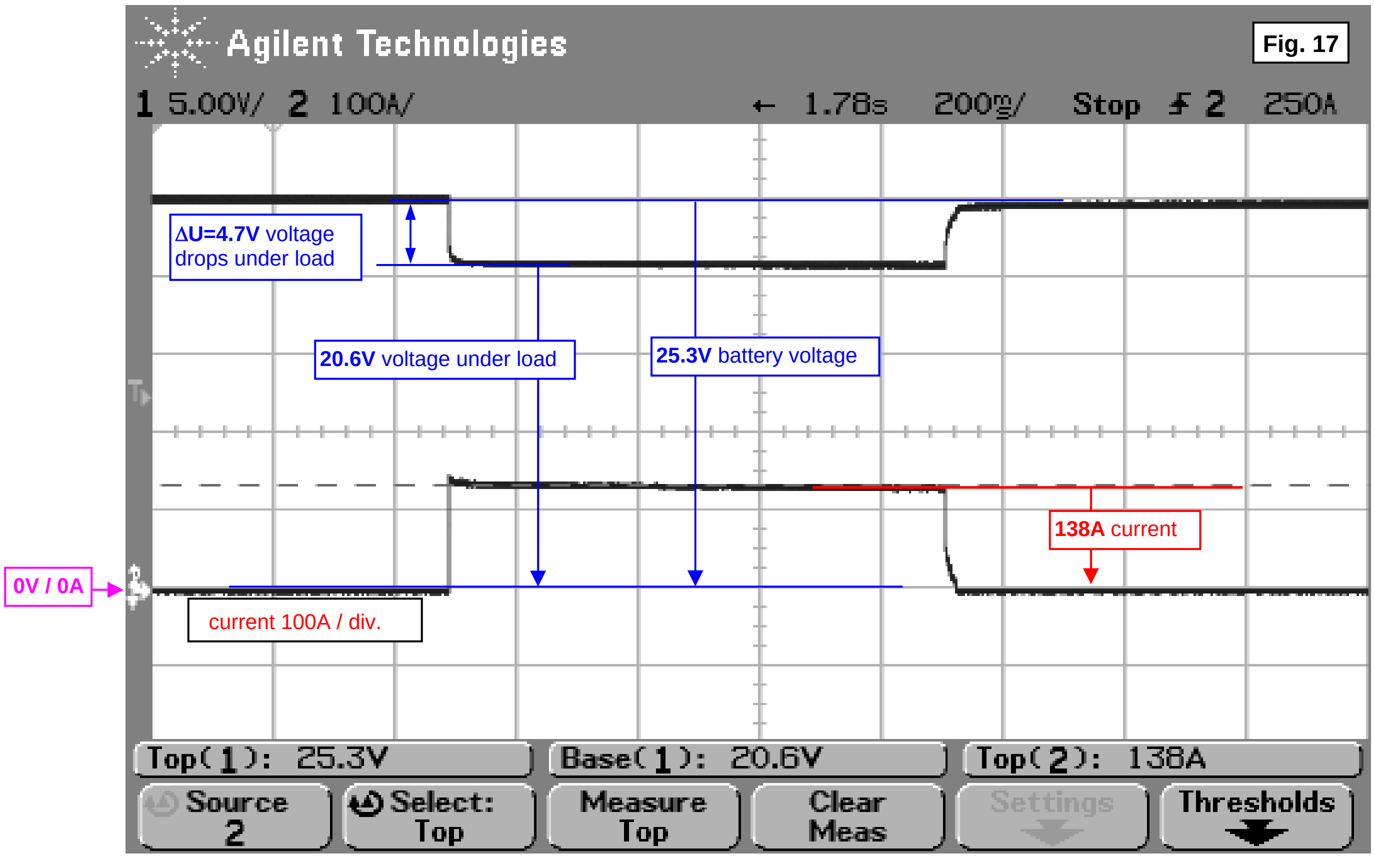
You can see on the next pages measure internal battery resistance by this method. Here was used oscilloscope for better clearness.

Examples with batteries with different inner resistances:

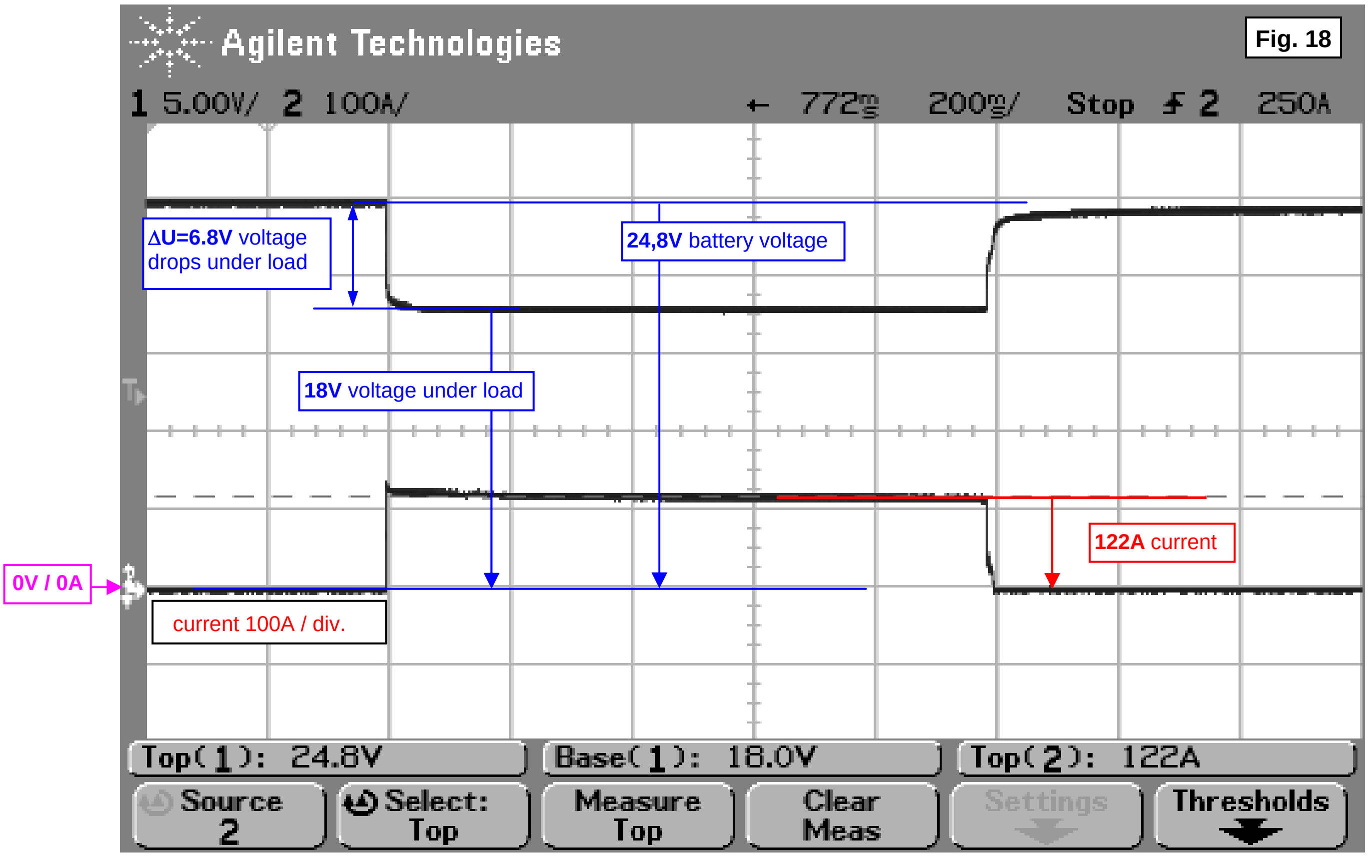
Battery A123, 2.3Ah, 7s, i.e. battery with 23V (3.3V/cell), total inner resistance $\mathbf{R_{inner}}$ **= 90 mΩ,** (i.e. 13 mΩ / cell).



Kokam 5000 mAh/30C, 6s, i.e. battery with 22V (3.7V/cell), total inner resistance $\mathbf{R_{inner}}$ **=34 mΩ,** (i.e. 5.7 mΩ / cell).



Kokam 4800 mAh/20C, 6s, i.e. battery with 22V (3.7V/cell), total inner resistance $\mathbf{R_{inner}}$ **=56 mΩ,** (i.e. 9.3 mΩ / cell).



Noname Lipol battery 5000 mAh, 6s, i.e. battery with 22V (3.7V/cell), total inner resistance $\mathbf{R_{inner}}$ **=156 mΩ,** (i.e. 26 mΩ / cell)