Energy Limiters in Naviga M Class Events.

Thoughts on their use

Rev 1.1 – 20 September 2017

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1 INTRODUCTION

As from the Technical Committee Meeting at the world championships on 23rd August 2017, the use of limiters has been approved for use in Naviga M class events from 1 January 2018. However, at the time of writing, the decissions on testing, calibration, energy levels etc. have not been decided. These will be discussed and voted upon by the country heads in due course.

It is my aim in this document to pull together my thoughts on the use of limiters in the hope that this may assist this discussion.

There are currently three limiters that I am aware of on the market. These are:-

1) KLW202/001 – Sold by Wozniak RC Tech (Klaudiusz Wozniak)
2) MDLE4 – Sold by MModels.eu (Miroslav Miletín)
3) eLim – Sold by mlm Solutions (Martin Marriott)

A comparison table can be found in Appendix A for these three limiters. The blanks in this chart will be filled in as soon as the information is provided to me by the respective suppliers.

Disclaimer: As the designer of the eLim I can speak with authority about it. I have not had the opportunity to use the other two limiters and my understanding of them comes only from the manufactures manual. If I have misrepresented them in any way, let me apologise in advance and say that I will correct my error at the earliest possible opportunity.

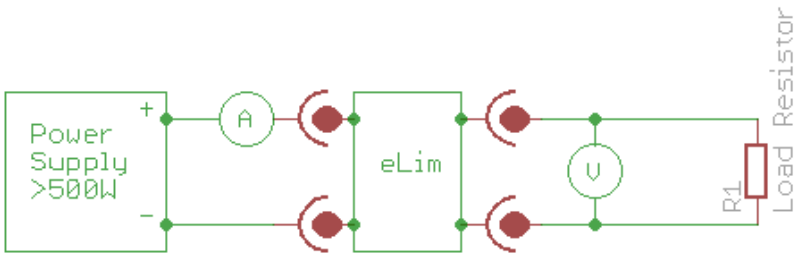
2 CHECKING ACCURACY.

In my view, it is important to be able to easily check the accuracy of a limiter. I believe that the easiest way this can be done is to be able to see what voltage and current the limiter is measuring. This allows the value to be compared to a reference voltmeter and ammeter.

2.1 CHECKING VOLTAGE AND CURRENT

One of my early concerns was calibration. I was aware that as a relatively low cost item, not a laboratory instrument (and even they need recalibrating from time to time), I did not want the user to have to return them for this to be done. I therefore allowed for calibration by the race organisers.

As this put the responsibility on to the race organisers, I wanted this to be as simple and cheap as possible to do. I assumed a set up as shown in the diagram below.



The load resistor should draw a realistic current. I assumed about 35Amps.

It should also be at a realistic but convenient voltage. I assumed 12Volts.

This means that the load would need to dissipate 12x35=420Watts and would have a resistance of 12/35=0.34Ohms. A cheap and effective method of achieving this is to use 8 or 9 domestic spotlights of 12V 50A rating which are readily available.

The power supply would therefore need to be approximately 12V and at least 500W capacity. This could most readily be achieved with a 3S LiPo although this is not ideal due to the need to constantly recharge it.

The voltmeter can be any bench meter of sufficient accuracy which are readily available.

The current meter is more difficult as most multi-meters only read up to about 10A without additional external hardware. However, it is my belief that the most important thing in a competition is not that the limiter is calibrated to international standards but rather that they are all identically calibrated in order to achieve fairness.

With that thought in mind, a standard 50A analogue meter could be used, which whilst not very accurate or linear, at a specific current they are very repeatable.

As far as I am aware, the only limiters that can currently do this are the eLim and KLW202/001.

2.2 Checking Energy used

As one of the limiters does not display voltage or current, then the accuracy must be checked by installing the limiter in a circuit similar to that shown above alongside a reference energy meter comparing the amount of energy used to the reference. In order to be accurate this has to be done over a reasonable time period. This makes checking at race meetings time consuming.

3 Calibration

If as a result of doing an accuracy check the limiter is found to be outside tolerance, then a decision needs to be made about what to do about it.

1) If it is an eLim then it can be recalibrated (see below)
2) If not then…. Perhaps reject the limiter.

3.1 How to calibrate at a race meeting

Note this is only possible with the eLim.

Given the setup described above, all the race organisers have to do is:-

1. Connect the eLim into the rig
2. Plug in the eLim programmer
3. On the voltage calibration screen of the programmer, set the voltage to read the same as the voltmeter.
4. On the current calibration screen of the programmer, set the current to read the same as the ammeter.

5. On the general screen of the programmer, do a long press of the select key and all predefined settings are transferred to the eLim along with the security code.

This whole process takes less than one minute.

If I am correct and neither the MDLE4 nor the KLW202/001 can be calibrated in the field, then there is nothing that the race organisers can do and they must therefore rely on the factory calibration being within a predefined tolerance. The benefit is that the race organisers will not require any test equipment and will only need a programmer for each limiter type in order to set the required ramp down time, limit time etc. For the eLim and the MDLE4 this would only appear to be done once per meeting but for the KLW202/001, as far as I can tell from the manual, it only has one stored energy limit and would therefore need to be reprogrammed if the entrant runs in a different energy band class.

3.2 CALIBRATION AT THE FACTORY

If the limiter can only be calibrated at the factory, there are some problems:-

1) The inconvenience of having to return the limiter for re calibration
2) The cost of re calibration
3) The suspicion by some racers that there may be some “specially calibrated” limiters.
4) If at a race meeting, the limiters are tested and some are found to be out of spec, there is nothing that can be done about it.

If they must be returned for recalibration, there are only two alternatives I can see.

1) The individual manufacturers must calibrate the limiters at the factory using the same methods and to an agreed tolerance.
2) The calibration of all limiters must be done by an independent third party.

If alternative 1 is chosen, then I think that a simple reproducible technique is used. A/C waveforms and high frequency modulation of the supply should be avoided and something simpler as described in section 1 should be adopted measuring a DC voltage and static current. I have described above how the eLim is calibrated but as I do not know how the other two limiters are calibrated, I will have to wait to hear feedback from Miroslav and Klaudiusz.

3.3 ALTERNATIVES TO CALIBRATION

Even if all limiters were all perfectly calibrated, there may still be racers who would not believe that some limiters were not “specially calibrated”.

For these racers maybe the only option that would satisfy them is if the race organisers supplied the limiters for the meeting and that these were picked out of a hat prior to each race. This has the benefit for the organisers that all calibration could be done prior to the event and not between races.

This would mean of course that cable lengths and connector types would need to be standardised. This needs careful thought as the eLim fits in the positive and negative line. The MDLE4 fits only in the positive lead (with a ground reference required) and the KLW202/001 fits in the negative line (with a positive reference required).

4 ENERGY LEVELS

To help with the discussion, here are some simple formulas for conversion between pack capacity and energy.

WHr = Cells * VperCell * Ahr
Wmin = Cells * VperCell * Ahr * 60
Ahr = WHr / (Cells * VperCell)
Ahr = Wmin / (Cells * VperCell * 60)

It will be noticed that these formulas contain the variable “VperCell”.

This is because the pack capacity only considers current and time.

The pack energy (WattMins or WattHrs) considers current, time plus voltage. A pack that can deliver 5000mAh at 12 volts will deliver more energy than one that delivers 5000mAh at 11.5 volts.

For International racing, it is my view that the energy limit must be as close as possible to the energy which can be obtained from the best packs that are available at the time. This is because some racers are either sponsored or can afford to use a new pack for each race. Bear in mind that the boats with Naviga legal packs will still have an advantage over boats with limiters due to the additional weight of the larger pack plus the limiter weight.

However, I can see that for club racing, setting the energy limit to be equivalent to the ‘best’ packs would mean that those who couldn’t afford to race with the ‘best packs, they would be virtually forced to use limiters to compete. Therefore, for club events, a lower limit may be used.

4.1 CALCULATED EQUIVALENCE

In my experience, a pack that is fully discharged over six minutes has an average cell voltage (“VperCell”) of 3.7 volts but this is open to discussion.

Capacity to energy equivalence table

	Per cell	Mini Classes		ECO, M1, H1 Classes		M2, H2 Classes		FSRE
Cells		2	3	2	3	4	6	9
Duration(mins)		6 .0	6.0	6.0	6.0	6.0	6.0	15.0
Nominal voltage under load	3.7	7.4	11.1	7.4	11.1	14.8	22.2	33.3
Cell capacity (A Hr)		2.7	1.75	7.2	5.05	7.2	5.05	5.05
Energy (Watt Hrs)		19.98	19.425	53.28	56.055	106.6	112.11	168.17
Energy (Watt Mins)		1198.8	1165.5	3196.8	3363.3	6393.6	6726.6	10090
Watts for Duration		199.8	194.3	532.8	560.6	1065.6	1121.1	672.7
Amps for Duration @ nominal voltage		27.0	17.5	72.0	50.5	72.0	50.5	20.2

The table above gives an indication of the energy that is available from currently available Naviga legal packs (Tenshock, Redzone, RoaringTop). And the energy that would theoretically be available if the stated capacity were true and the average discharge voltage were 3.7V per cell.

To summarise:-

Suggested Energy Limits	(WattMins)	(WattHrs)
Mini	1200	20
ECO, M1, H1	3360	56
M2, H2	6720	112
FSRE	10080	168

Note that only the eLim measures in WattMins. The KLW202/001 measures in WattHrs to a resolution of 0.1 WattHrs (6 times coarser) and the MDLE4 measures to a resolution of 1 WattHr (60 times coarser). This means that for all limiters to be compatible, the limit chosen has to be rounded to a whole WattHr.

For those that would prefer a table to a formula, please see Appendix B.

4.2 Measured equivalence

As an alternative to the calculated limit shown above, the other way of determining the energy limits would be by experiment using a random sample of new Naviga legal packs.

Simply charge the pack to the maximum voltage allowed (4.23 volts) and discharge it to the minimum voltage allowed (3.0 volts) using a realistic load that would discharge the pack in about 6 minutes. If the discharge occurred through the energy limiters, they would show how much energy had been consumed.

I use the voltages stated above as these are the voltages that are allowed and some will use even though I do not personally recommend it due to its effect on battery life.

In a real world test using Redzone 5050 3S packs, an average energy (measured by an eLim) of approximately 3300WattMins was recorded. This was admittedly with a small sample size and more results need to be taken to get a more accurate value.

4.3 Tracking of Energy Levels with increases in cell capacity

It seems clear to me that the limiter energy levels need to be increased in line with any increase in capacity from the battery manufactures.

In order to avoid any delay in this new limit being approved which would be the case if we had to wait for a vote at the bi-annual world championships, the limit could be defined by a formula rather than an absolute value. i.e.

WattHr = Cells * 3.7 * Ahr

Where Ahr is the maximum capacity Naviga legal cell currently available.

5 Other Configurable Options

5.1 Ramp down Time

This is the time taken to decrease the throttle from its maximum value to its minimum value when the energy limit is reached.

My view is that this time should be long enough for the racer to recognise that the limit has been reached and move off the racing line but should be short enough that they cannot continue racing. Given that a lap in some classes may be 12 seconds, I find that a ramp down time of 3 seconds is about right.

The eLim has the most restrictive option (0-9 secs). Therefore, for compatibility with all limiters, 9 seconds is the maximum ramp down time.

5.2 LIMIT TIME

This is the time that the limiter will hold the throttle at its minimum value before re-enabling it.

This time needs to be long enough for it to be obvious that the limit has been reached but short enough not to interfere with the following race.

About 120 seconds seems a good value.

The MDLE4 has the most restrictive limit time. Therefore, for compatibility with all limiters, 120 seconds is the maximum limit time.

5.3 LIMITED THROTTLE SETTING

This is the percentage of the throttle range (max-min) that the throttle will be limited to during the "limit time". I.e. if this was set to 30%, then during "limit time", the racer could still drive the boat at up to 30% throttle. This was provided as some racers were concerned that the boat would be disabled on the racing line.

Note however that this feature is only available on the eLim and so to be compatible with the other limiters, it would need to be set to 0%

6 POTENTIAL FOR MISUSE

The following represent the possible ways I can think of that cheating might be possible. Please let me know if you can think of others.

6.1 ELIM

When the eLim programmer is used to configure or calibrate an eLim, a four digit code is sent to the eLim which is stored even after power off. Whenever the eLim is connected to a programmer, this code is echoed back to the programmer and if it does not match the one that the programmer has then this will be indicated on the programmer. Therefore if any other programmer was used to change anything since the last time the race organisers programmer was connected then it will be displayed.

As long as at a race meeting the eLim is configured with the programmer with a password set, then believe it to be impossible to change these settings without being able to be detected. However, one possible way to cheat would be to select let's say the mono2 energy band when in a mono1 race. To avoid this, the eLim must remain powered and checked after the race (use the eLimView to check the energy consumed).

6.2 MDLE4

As with the eLim, one possible way to cheat would be to select let's say the mono2 energy band when in a mono1 race. To avoid this, the MDLE4 must remain powered and checked after the race.

The MDLE4 can be reprogrammed with the MDPL1 programming card. This is only available to "*national section leaders/trainers or any other chosen responsible person*". One

programming card cannot as far as I know detect if another has changed a setting. This is fine as long as all national leaders trust each other.

6.3 KLW202/001

As with the eLim and MDLE4, one possible way to cheat would be to select let's say the mono2 energy band when in a mono1 race. To avoid this, the KLW202/001 must remain powered and checked after the race.

The KLW202/001 can be programmed with a memory key that is configured with a "Judge Option" version of the KLW202. This is password protected. However, whilst the limiter cannot be programmed with another memory key now, all you have to do is leave the limiter powered for one hour and it is reset so that ANY memory key will reprogram it.

As the KLW202 can only hold one energy limit at a time (it needs the memory key to change it) and because it resets after being powered for one hour, the organisers would need to set it before every race.

6.4 ALL

All the limiters re-enable the throttle after the "limit time". It would be possible (though unlikely) that the race is still going on when it is re-enabled and that the racer could continue racing. As long the "Limit Time" is sufficiently long then the racer would be unlikely to be competitive. Care would need to be taken in races that are paused as the "Limit Time" could time out during the paused period.

With all limiters the racer could leave the esc connected to the receiver and not pass the signal through the limiter.

7 CONCLUSIONS

To summarise the above, my recommendations would be:-

7.1 ENERGY LIMIT

For international events there should be a level playing field between Navigal legal packs and limiters. The energy level set should be the same as the highest capacity Naviga legal packs available at the time. This should be defined by measuring the energy in a random sample of these packs (let us say 10 minimum) and averaging the result. This will need to be rounded to the nearest Watt Hour. I believe that this should be rounded up to compensate for the additional weigh incurred.

7.2 RAMP DOWN TIME

In order to be compatible with all limiters, the ramp down time must be within 1-9 seconds inclusive. We have found that 3 seconds is fine.

7.3 LIMIT TIME

In order to be compatible with all limiters, the limit time must be within 1-120 seconds inclusive. A limit time of 60 seconds is fine as long as after the limit time, no more line crossings occur.

7.4 LIMITED THROTTLE SETTING

Only one limiter allows this to be changed. In order to be compatible with all limiters, it must therefore be set to zero.

7.5 SHOULD THE ENERGY LIMIT VALUE BE CHANGED PERIODICALLY?

The limit should be reviewed by a “technical committee” whenever the capacity of Naviga legal packs increases.

7.6 CHECK IN/OUT CONTROL

Checks must be made before or after the race to see that:-

1) The limiter is connected before the safety loop
2) The limiter is correctly connected between the receiver and the ESC.
3) The correct limit for the class being raced is set.
4) Check that the limiter is correctly configured.
    a. The eLim needs to be plugged into the race control programmer to see if it has been changed by another programmer.
    b. The MDLE4 needs to be programmed each time as it can be changed by any programmer.
    c. The KLW202 needs to be programmed each time as it can be reset by leaving it powered for one hour.

7.7 CHECK ACCURACY

Not all limiters can display the voltage and current readings and so this method cannot be used to check accuracy. This would have to be done by testing them with an inline reference energy meter over a period of time.

To save time this could be done only for the top three boats.

Alternatively the limiters could be picked from a hat.

8 APPENDIX A – COMPARISON CHART

	eLim	MDLE4	KLW202/001
Supplier	mlm Solutions	MModels.eu	Wozniak RC Tech
Design Contact	Martin Marriott	Miroslav Miletín	Klaudiusz Wozniak
Max Input Voltage (V)	60	45	40
Max Current (continuous) (A)	100	160	100
Max Current (peak) (A)	160	?	200
Voltage Resolution (mV)	4	?	?
Current Resolution (mA)	20	?	?
Energy Resolution (WattMins)	1	?	6
Voltage Accuracy	<0.3%	+/-0.5%	?
Current Accuracy	<0.3%	+/-1%	?
Energy Accuracy	<0.6%	?	2% >5A
Sample Rate (Hz)	800	25	?
Ramp Down Time (Secs)	0-9	1-20	0-30
Limited Throttle (%)	0-99	0 fixed	0 fixed
Limit Time (Secs)	0-999	1-120	0-999
Selectable Energy Levels	4 (with supplied button)	4 (with MDPL2 button, sold seperately)	1
Max' Energy Level (WattMins)	65535	12,000 (in steps of 60)	2,280,000 (in steps of 60)
Can display measured voltage?	Yes (with eLim Programmer or eLim View)	No	Yes
Can display measured current?	Yes (with eLim Programmer or eLim View)	No	Yes
Can display used energy?	Yes (with eLim Programmer or eLim View. Shows energy used.)	Yes (using on board single digit display. Shows remaining energy)	Yes (using on board 3 digit display. Shows energy used)
Can be calibrated in the field?	Yes (with eLim Programmer)	No	No
Can pre-programmed energy levels be changed?	Yes (with eLim Programmer)	Yes (with MDPL1 card)	Yes (with "judge" option)
Waterproof	Yes	Yes	Yes
Size (Y X Z mm)	30x28x8	31x35x7	31x45x12
Weight (gm) with cable	25	27	35
Weight (gm) without cable	8	10	?

9 APPENDIX B – WATT HRS TO AMP HOURS EQUIVALENCE

The table below shows the equivalence of WattHrs to AmpHrs for the Mini classes and Mono1/Hydro1 classes using an assumed average discharge voltage of 3.7V.

The coarser WattHr increments will have to be used as only one limiter can be set in WattMins.

Assumed VperCell 3.7

	AmpHrs	
WHr	**2S**	**3S**
19	2.568	1.712
20	2.703	1.802
21	2.838	1.892
53	7.162	4.775
54	7.297	4.865
55	7.432	4.955
56	7.568	5.045