Down Hole Power & Drilling Instrumentation.
"Performance beyond Expectation"

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PolyComm 100 Watt alternator transient stability test report.

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1.0) Introduction.

Any electrical power source delivers power in the form of Volts x Amps and a down hole mud alternator is no different in this respect. What separates good power sources from bad ones is line regulation, load regulation and stability. Line stability is a measure of the power source's ability to maintain a constant output voltage in the face of input disturbances. For a battery this would be temperature, aging or even its own decaying chemistry as it discharges. For an active machine like an alternator, it would be speed changes caused by variations in wind speed for a wind turbine, steam pressure for a power station or mud flow for a mud alternator. Load regulation is a similar measurement taken from the alternator to assess its ability to maintain its output voltage under full load conditions and is related to its output impedance or resistance. Voltage sources like lead acid batteries or powerful alternators need very low output impedance (or resistance) to demonstrate very good load regulation. By this definition, a perfect voltage source has zero output impedance (or resistance) and all voltage sources are measured against this ideal.

For a mud alternator, Line regulation can be determined by varying the mud flow rate and measuring the change in output. Because most open loop alternators use switch mode power supplies to convert the large scale changes in input voltage to a constant output voltage for the down stream electronics, line regulation is usually very good with this approach; the switch mode effectively masking the worst excesses of the open loop alternator. However, load regulation is more difficult to achieve via this route especially when the specification is 100 Watts at 150ºC. Under these conditions, the mud alternator's switch mode power supplies can struggle to cope with the stress and strain of high load demand, high temperature and high flow rate all at the same time. Predictably, the reliability of the machine is compromised under these stressful operating conditions.

Load regulation is a measure of the power source's output impedance (or resistance) and this can be measured with a simple drop test. A drop test measures the difference between the open circuit voltage and the fully loaded voltage and calculates the output resistance based upon (Vo/c – Vc/c)/Iload. A perfect voltage source will return zero for (Vo/c – Vc/c) and therefore the output resistance will be zero. For all other real machines a residual resistance will be measured and the closer to zero Ohms measured, the better the machine.

For open loop alternators, the output resistance is the consequence of a number of machine variables including its physical size, the strength of the magnets, output voltage at a particular rpm, power rating etc, and only a fundamental redesign of the machine will change this figure. However, by closing the loop around a conventional alternator, the actual output resistance can be dramatically reduced creating all sorts of other instrumentation possibilities for a closed loop machine, possibilities that open loop machines would find difficult, if not impossible to reproduce in the field.

The oscilloscope plots presented in this report demonstrate that once sufficient flow rate had been achieved to maintain full load, the closed loop performance of the PolyComm alternator guaranteed very low output resistance and the machine approached the ideal of a perfect voltage source irrespective of flow rate or load. Although not reproduced here, spreadsheet data confirmed that the open loop output resistance of the alternator was reduced thirty times to less than one Ohm, allowing the instrument to be considered for alternative, high power uses within an Oilfield environment. One of the most obvious applications is EM Telemetry where this tool's very low output resistance and high output power capability would be well matched against the very low formation resistances encountered down hole or sub sea.

2.0) Open and Closed Loop Basics.

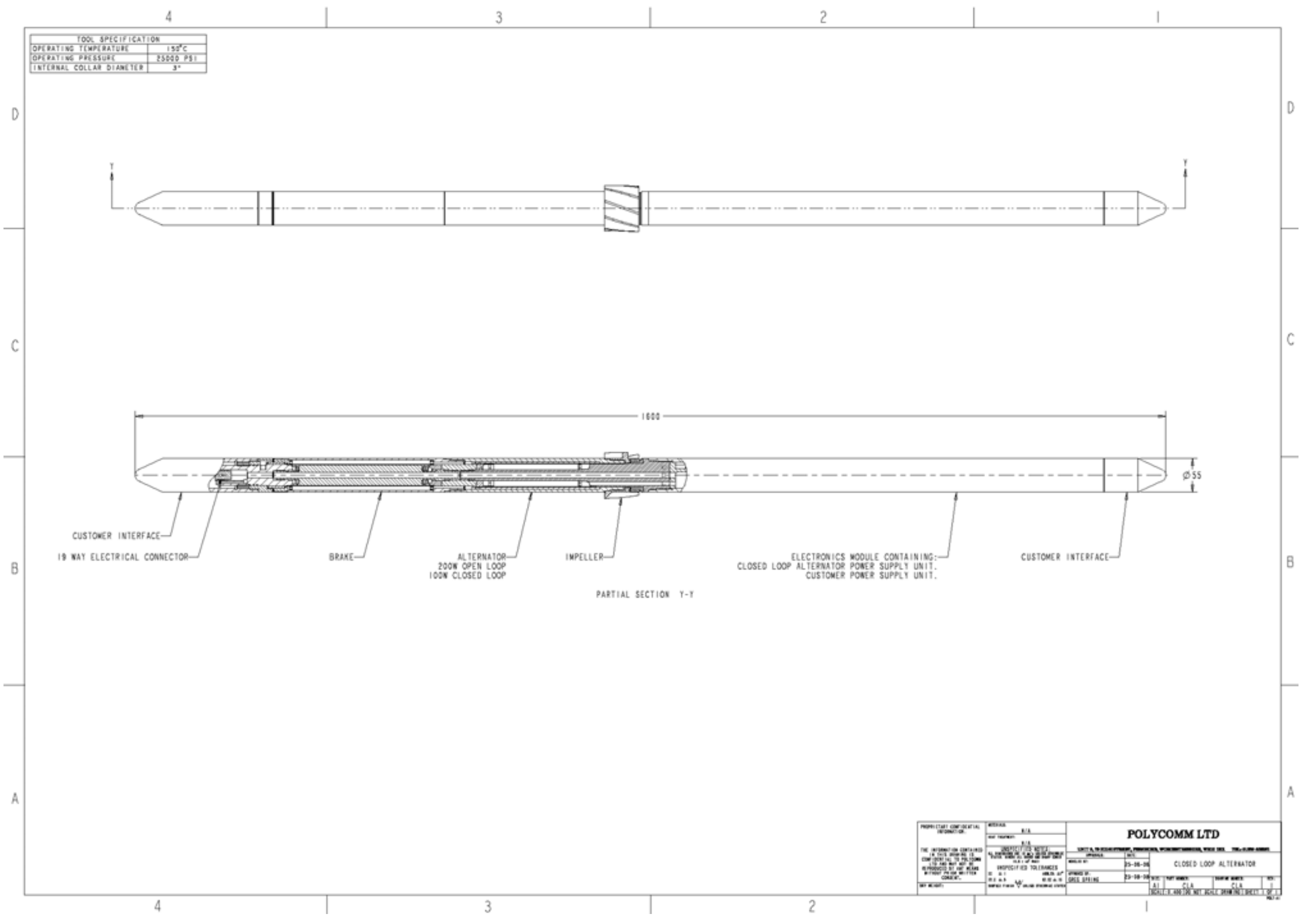
With the exception of some aerofoil wings and magnets, all open loop systems are unconditionally stable. Closed loop systems can be anything from unconditionally unstable to unconditionally stable and therefore much more care is required with a closed loop system to ensure it remains unconditionally stable under all operating conditions. Well behaved transient characteristics are also a fundamental requirement of any closed loop system and the closed loop alternator described in this document has been designed to be unconditionally stable and demonstrate outstanding loop dynamics against severe changes in load and flow rate.

3.0) Open and Closed Loop Alternator Facts.

All mud alternators extract their power from the mud flow through the turbine blades of the impeller. Output power is therefore inextricably linked to flow rate; the higher the flow rate, the more power can be extracted from the mud. The PolyComm alternator therefore only maintains a regulated closed loop output voltage when there is sufficient power in the mud to maintain full voltage at full load. The alternator dropped out of regulation and behaved as a conventional open loop alternator when either the load was too severe and/or when the flow rate was too low to maintain output. As the following plots will illustrate, this process of dropping in and out of closed loop regulation happened automatically and transparently. The reader should note that at all times, the alternator automatically responded to these changes and defaulted to the closed loop condition whenever flow and load conditions allowed.

4.0) <u>Tool Dimensions and Flow Loop Test Conditions.</u>

The 100 Watt closed loop alternator used for these tests was 55mm OD x 1600mm long and fitted with a 76mm OD x 30 degree impeller, designed for a 3” ID collar. The alternator was flow tested from 200GPM – 600GPM at normal temperature and atmospheric pressure using a water glycol mix to replace drilling mud which wasn’t available for these tests. Three loads selected for these tests were open circuit, 10R and 5R. A 1000uF, 200V reservoir capacitor was used to smooth the 30V regulated output.



<u>Fig 1: Partial cut away drawing of the closed loop alternator used for these tests.</u>

5.0) <u>Line and Load Stability Plots.</u>

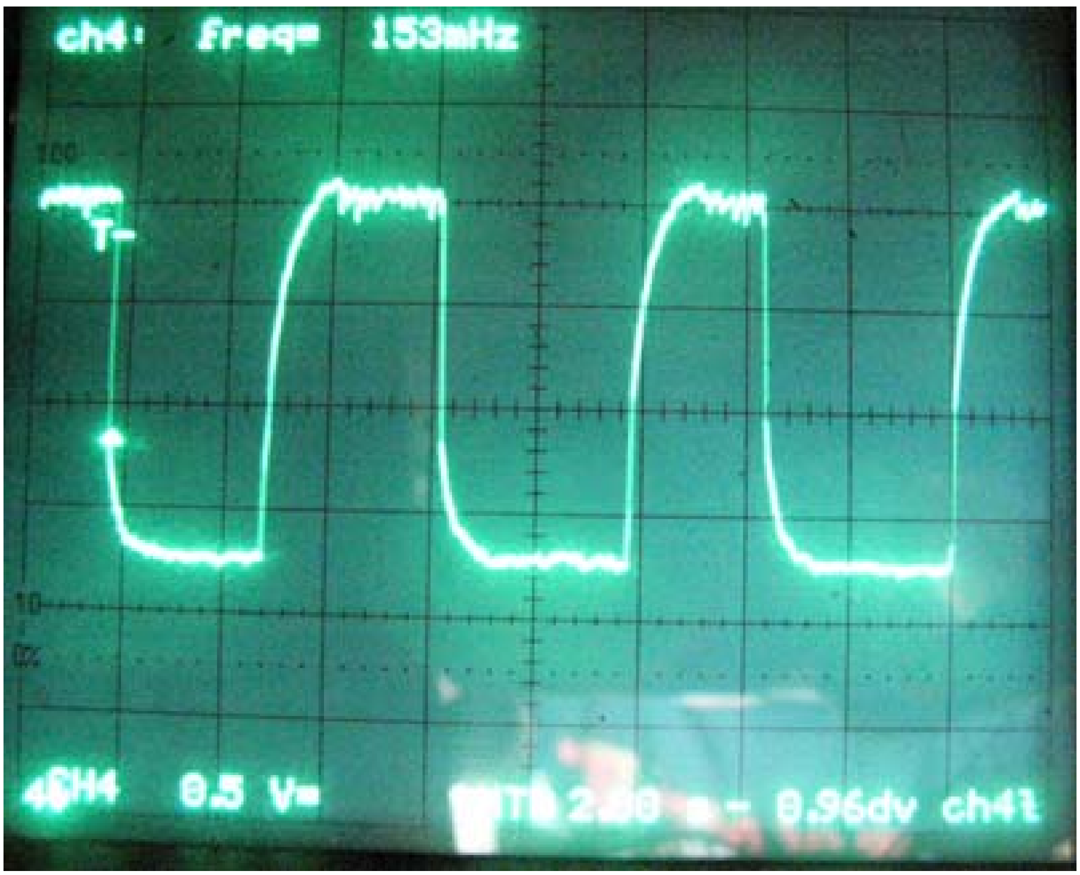
The following oscilloscope traces were taken to test the transient performance and stability of the closed loop alternator at different flow rates when subjected to full load and twice full load. It is recognised that at low flow rates there was insufficient energy in the flow to maintain these load demands, but the measurements were taken nonetheless to illustrate how the machine behaved under these extreme conditions. As would be expected, the performance of the machine improved with flow rate due to the higher levels of intrinsic energy in the flow. These plots record the behaviour of the machine in open and closed loop mode when subjected to full and twice full load tests. It should be noted that the 200GPM test results were omitted from this report because the alternator stalled and therefore produced no output when either the full load or twice full load was presented. Clearly there was insufficient energy in this flow rate to sustain either of these load demands.

6.0) Transient and Stability Data.

6.1) 250GPM, Full Load Open & Closed Loop

Fig 2 illustrates the performance of the alternator at 250GPM subjected to a series of 90 Watt drop tests. This simple test alternatively applied no load and full load at conveniently spaced time intervals to record the transient behaviour and stability of the machine under these test conditions. The top of the trace is the no load closed loop regulated output of 30V and the bottom of the trace is the open loop loaded output voltage of 12V5. Note that for all these tests, if the output voltage fell below 30V, the alternator dropped out of closed loop regulation and behaved as a conventional open loop alternator for the duration of the excessive load. This trace showed the alternator was unable to maintain a 30V regulated output when connected to a 10R load with a flow rate of only 250GPM, or in other words, 250GPM could not support 90 Watts. Despite this loss of closed loop control under load, the alternator demonstrated excellent recovery transient dynamics.

Conclusion: 250GPM cannot support 90 Watts load.



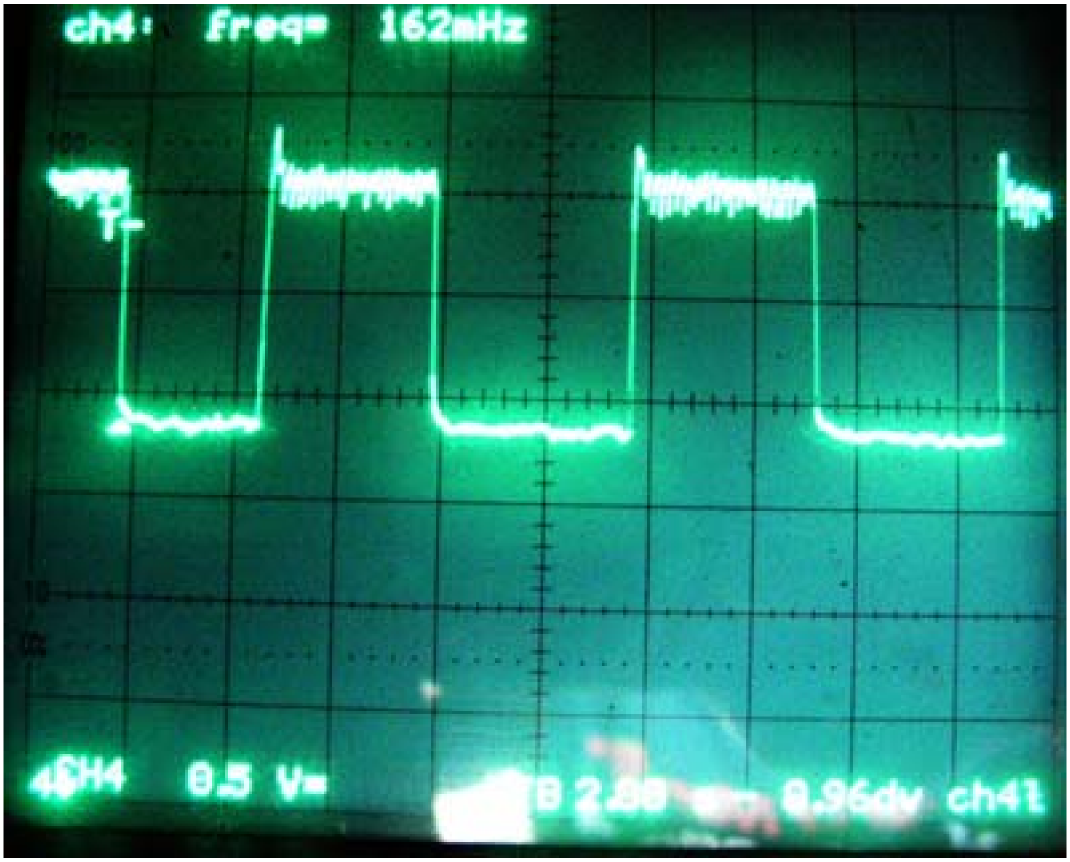
Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 2: Transient and stability performance for 90 Watts at 250GPM.

6.2) 300GPM, Full Load Open & Closed loop

Fig 3 illustrates the performance of the alternator at 300GPM subjected to the same simple series of 90 Watt drop tests. The top of the trace is the no load closed loop regulated output of 30V and the bottom of the trace is the open loop loaded output voltage of 18V5. Because the output voltage fell below 30V, the alternator dropped out of closed loop regulation and behaved as a conventional open loop alternator for the duration of the excessive load. This trace showed the alternator was unable to maintain a 30V regulated output when connected to a 10R load with a flow rate of only 300GPM, or in other words, 300GPM could not support 90 Watts. However, it should be noted that the open loop voltage was higher than the 250GPM test as would be expected from the higher intrinsic energy levels in the flow loop fluid. Again, the alternator demonstrated excellent transient dynamics under these test conditions.

Conclusion: 300GPM cannot support 90 Watts in regulation.



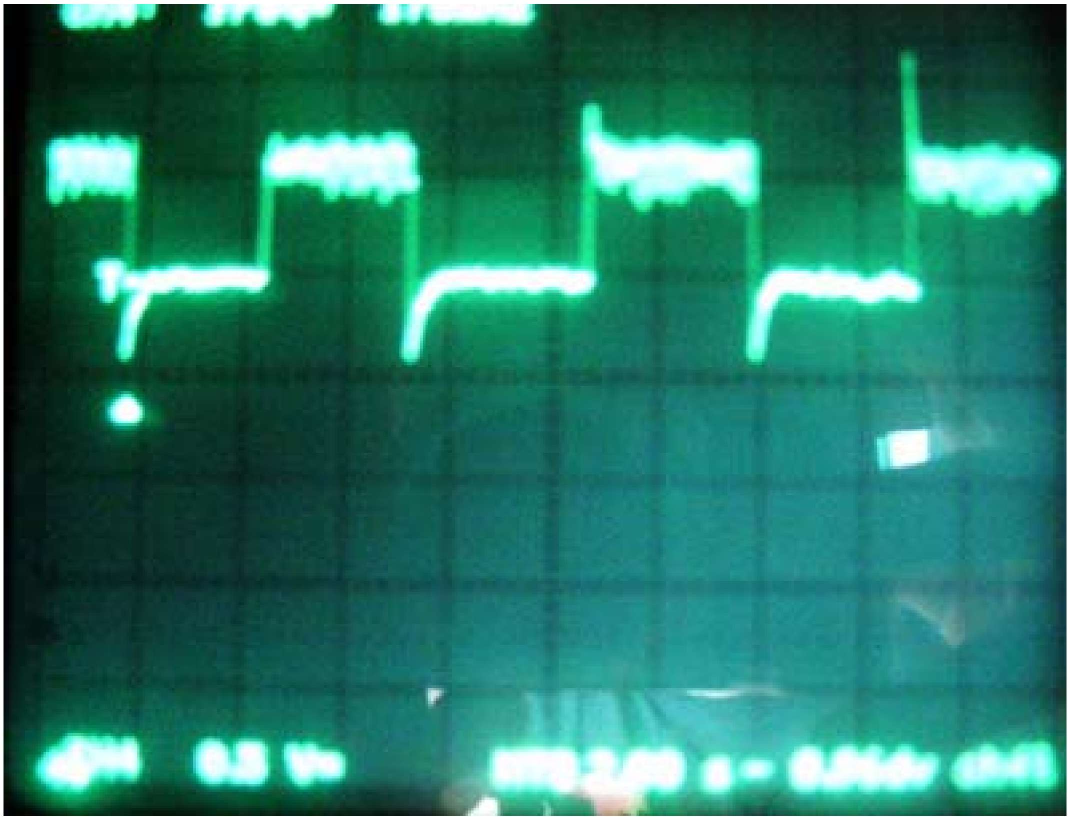
Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 3: Transient performance for 90 Watts at 300GPM.

6.3) 350GPM, Full Load Open & Closed loop.

Fig 4 illustrates the performance of the alternator at 350GPM subjected to the same simple series of 90 Watt drop tests. The top of the trace is the no load closed loop regulated output of 30V and the bottom of the trace is the open loop loaded output voltage of 25V. Again, because the output voltage fell below 30V, the alternator dropped out of closed loop regulation and behaved as a conventional open loop alternator for the duration of the excessive load. This trace showed the alternator was unable to maintain a 30V regulated output when connected to a 10R load with a flow rate of 350GPM, or in other words, 350GPM could not support 90 Watts. It should be noted that the open loop voltage was again higher than the 300GPM test as would be expected from higher intrinsic energy levels in the flow loop fluid and again, the alternator demonstrated excellent transient dynamics under these test conditions.

Conclusion: 350GPM cannot support 90 Watts in regulation.



Horizontal scale = 2s per div. Vertical scale = 5V per div.

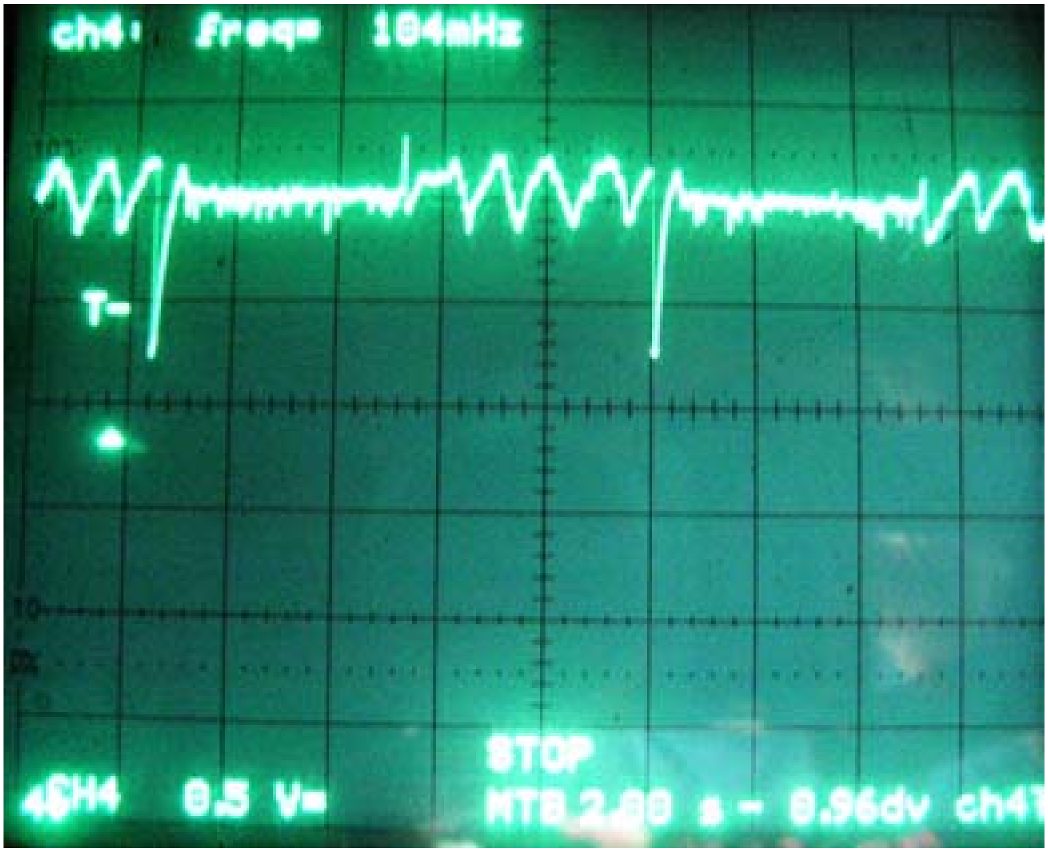
Fig 4: Transient performance for 90 Watts at 350GPM.

6.4) 400GPM, Full Load Open & Closed loop.

Fig 5 illustrates the performance of the alternator at 400GPM subjected to the same simple series of 90 Watt drop tests, but this time was able to maintain a regulated 30V output against this sudden load. This plot proved there was sufficient intrinsic energy in the 400GPM flow rate to maintain this load and keep the machine in closed loop regulation. From this point on, all 90 Watt test data will show the alternator maintaining closed loop regulation with this output load. Again, the alternator demonstrated excellent transient dynamics under these test conditions.

Note that the digital scope used for recording these plots sometimes produced an aliased representation of the actual alternator output as in this case. Aliasing is a digital sampling error related to Nyquist's sampling theorem which predicts when false low frequency signals are reproduced from an original high frequency signal as illustrated by fig 5. The frequency of the 30V rectified noise was too high for the sampling period and the digital scope created a sub harmonic of the original signal giving the impression of a sampled low frequency signal. Figs 7, 8, 9, 10 & 11 illustrate the actual high frequency rectified noise on top of the 30V DC rail and other images produced in this document which have a similar appearance to fig 5 have all suffered aliasing errors. To summarise, the alternator did not drop into a low frequency oscillation under load as suggested by the aliased plots of fig 5, 6 & 12.

Conclusion: 400GPM can support 90 Watts in regulation.

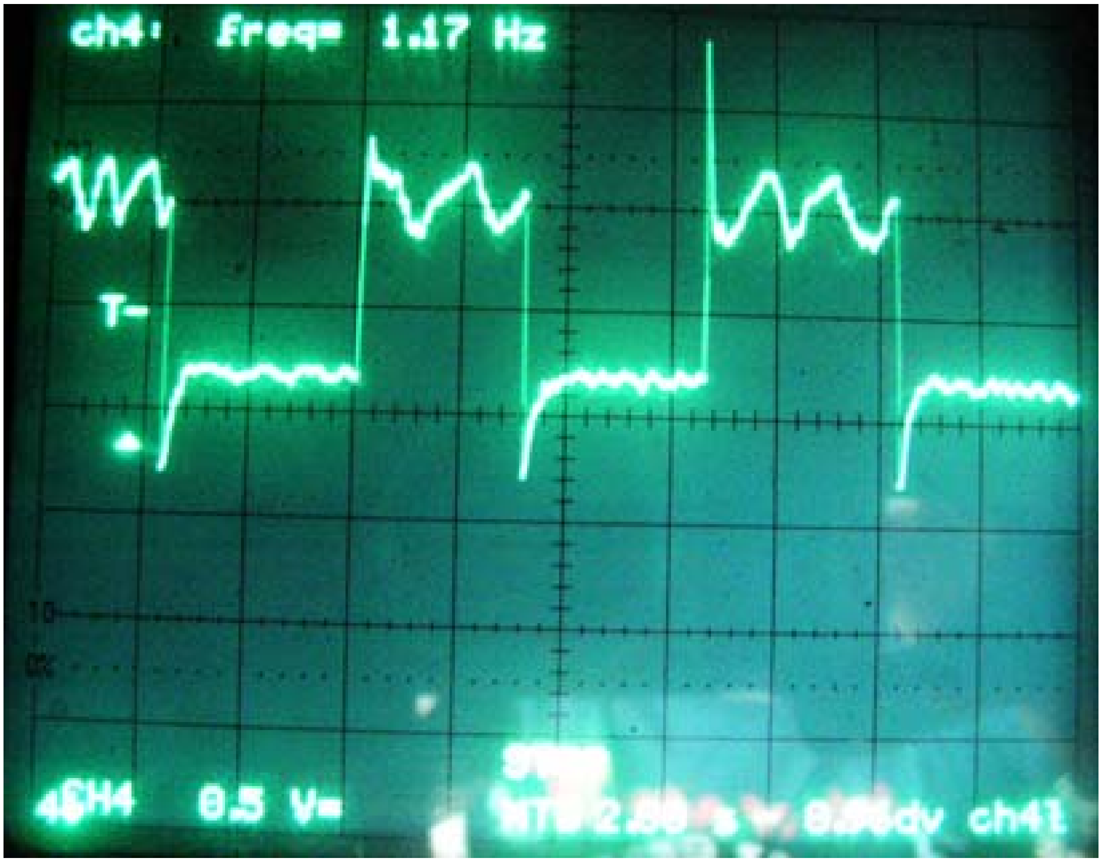


Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 5: Transient performance for 90 Watts at 400GPM.

6.5) 400GPM, Twice full Load Open & Closed loop.
Fig 6 illustrates the performance of the alternator at 400GPM subjected to a drop test load of 180 Watts. Because the last test proved the alternator could remain in regulation for a 90 Watt load at 400GPM, this new test was used to determine how the alternator would react to twice full load. The top of the trace is the aliased no load closed loop regulated output of 30V and the bottom of the trace is the open loop loaded output voltage of 22V. This test proved the alternator was unable to sustain 180 Watts at 30V under these flow conditions and dropped out of closed loop regulation for the time the excess load was present. Despite this loss of control under load, the alternator still demonstrated excellent transient recovery dynamics.

Conclusion: 400GPM cannot support 180 Watts in regulation.



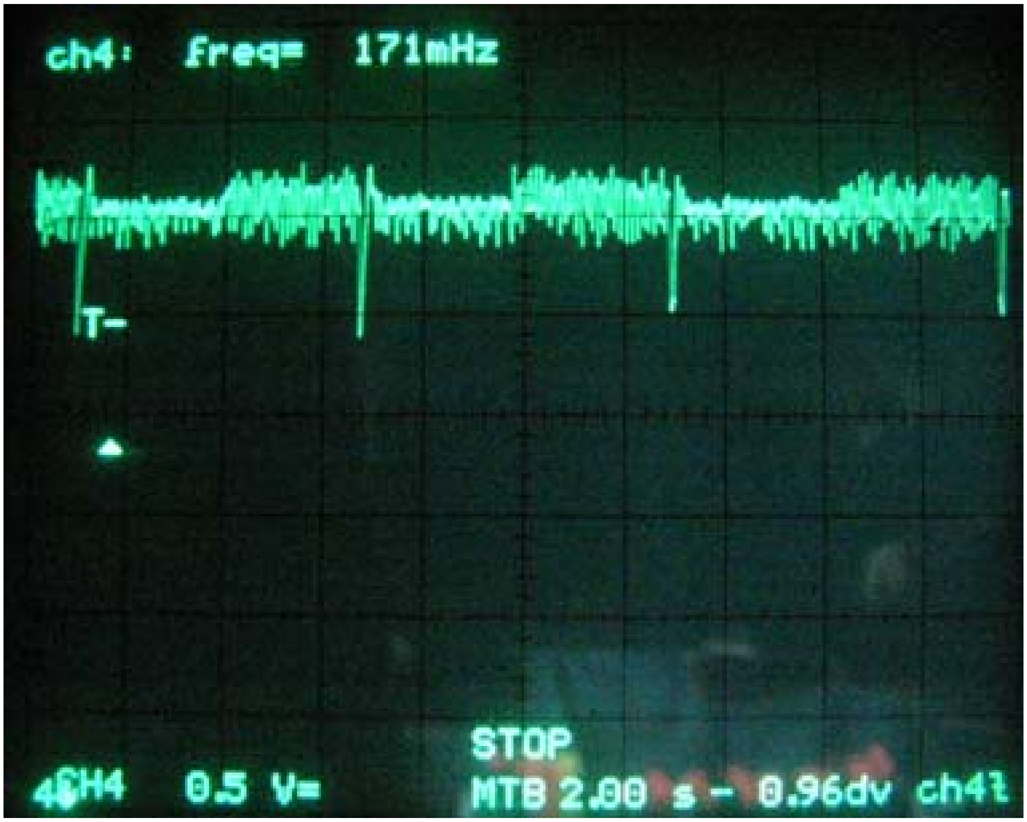
Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 6: Transient performance for 180 Watts at 400GPM.

6.6) 450GPM, Full Load Open & Closed loop.

Fig 7 illustrates the performance of the alternator at 450GPM subjected to the same simple series of 90 Watt drop tests and again the alternator was able to maintain a regulated 30V output with a 90 Watts load. Note that aliasing is not present in this image, the digital scope managing to take a faithful picture of regulated line noise under both load and no load conditions. Excellent transient dynamics under these test conditions was again proved.

Conclusion: 450GPM can support 90 Watts in regulation.



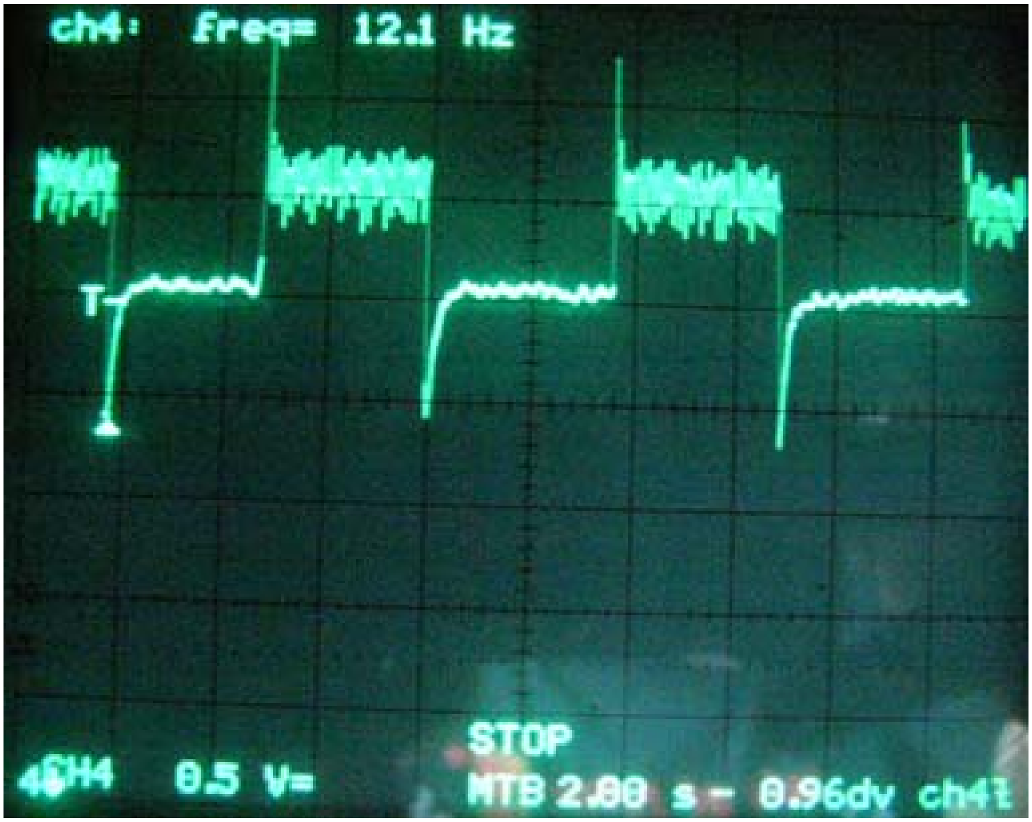
Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 7: Transient performance for 90 Watts at 450GPM.

6.7) 450GPM, Twice full Load Open & Closed loop.

Fig 8 illustrates the performance of the alternator at 450GPM subjected to a drop test load of twice full load (180 Watts). The top of the trace is the no load closed loop regulated output of 30V and the bottom of the trace is the open loop loaded output voltage of 25V. This test proved the alternator was unable to sustain 180 Watts at 30V under these flow conditions and dropped out of closed loop regulation for the duration the excess load was present. Despite this loss of closed loop control under load, the alternator still demonstrated excellent transient recovery dynamics and no aliasing problems were recorded with this image.

Conclusion: 450GPM cannot support 180 Watts in regulation.

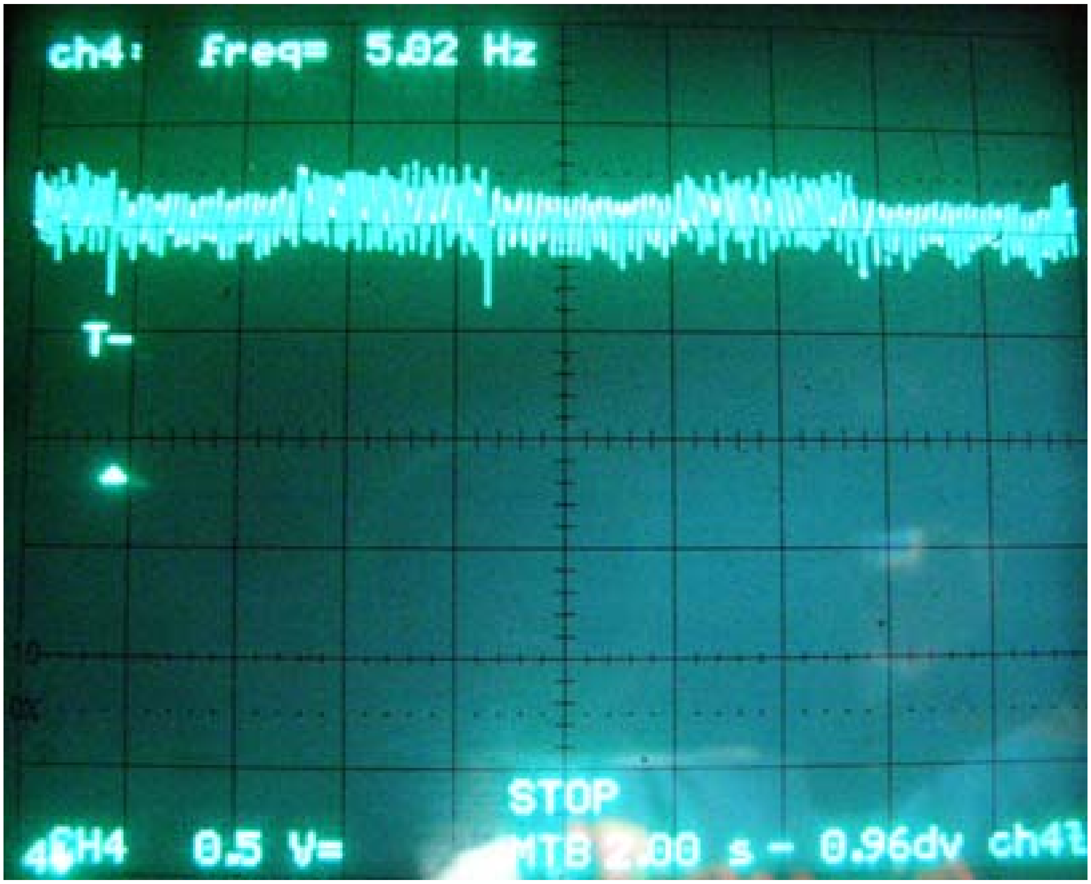


Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 8: Transient performance for 180 Watts at 450GPM.

6.8) 500GPM, Full Load Open & Closed loop.
Fig 9 illustrates the performance of the alternator at 500GPM subjected to the same simple series of 90 Watt drop tests and again the alternator was able to maintain a regulated 30V output and a 90 Watts load with excellent transient dynamics under these test conditions. This image is a faithful reproduction with no aliasing errors.

Conclusion: 500GPM can support 90 Watts in regulation.

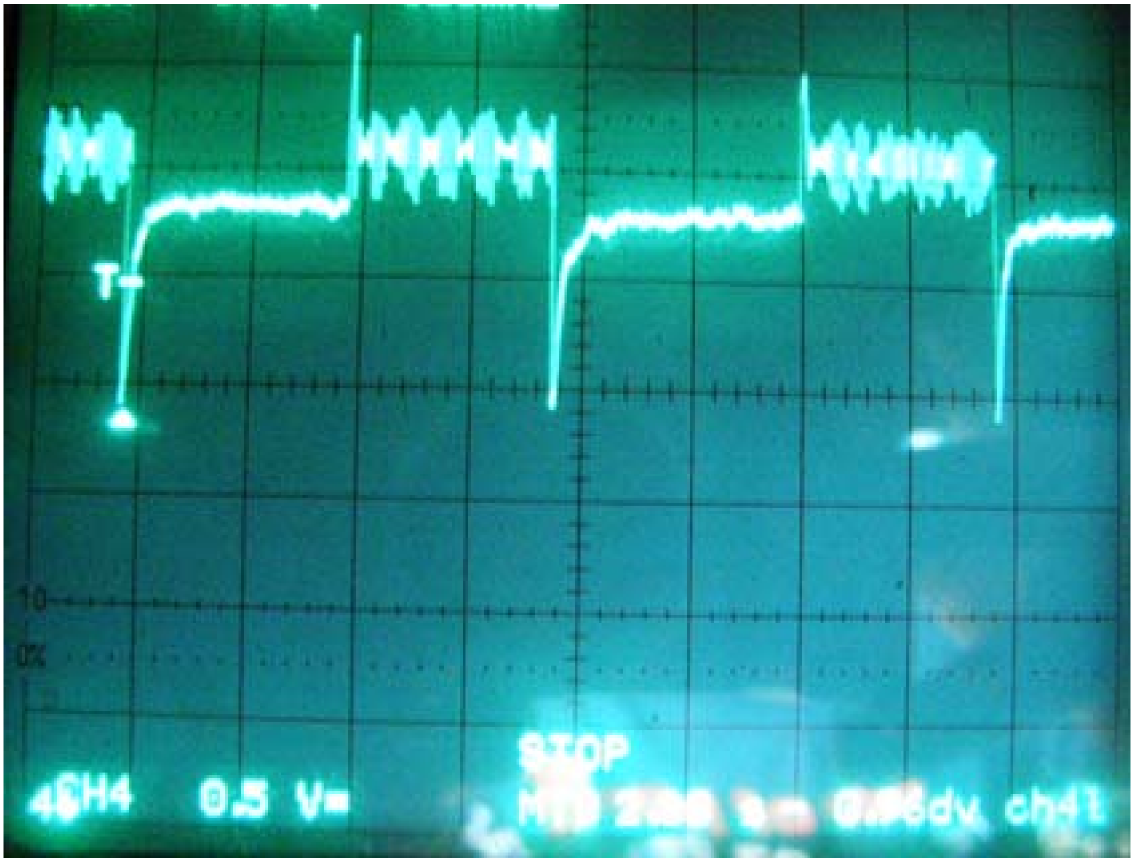


Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 9: Transient performance for 90 Watts at 500GPM.

6.9) 500GPM, Twice full Load Open & Closed loop.
Fig 10 illustrates the performance of the alternator at 500GPM subjected to a twice full load drop test of 180 Watts. The top of the trace is the no load closed loop regulated output of 30V and the bottom of the trace is the open loop loaded output voltage of 27V5. This test proved the alternator was unable to sustain 180 Watts at 30V under these flow conditions and dropped out of closed loop regulation for the duration the excess load was present. Despite this loss of closed loop control under load, the alternator still demonstrated excellent recovery transient dynamics. Note that as with the 90 Watts test, the alternator's open loop voltage continued to improve with flow rate due to the higher levels of intrinsic energy in the fluid.

Conclusion: 500GPM cannot support 180 Watts in regulation.



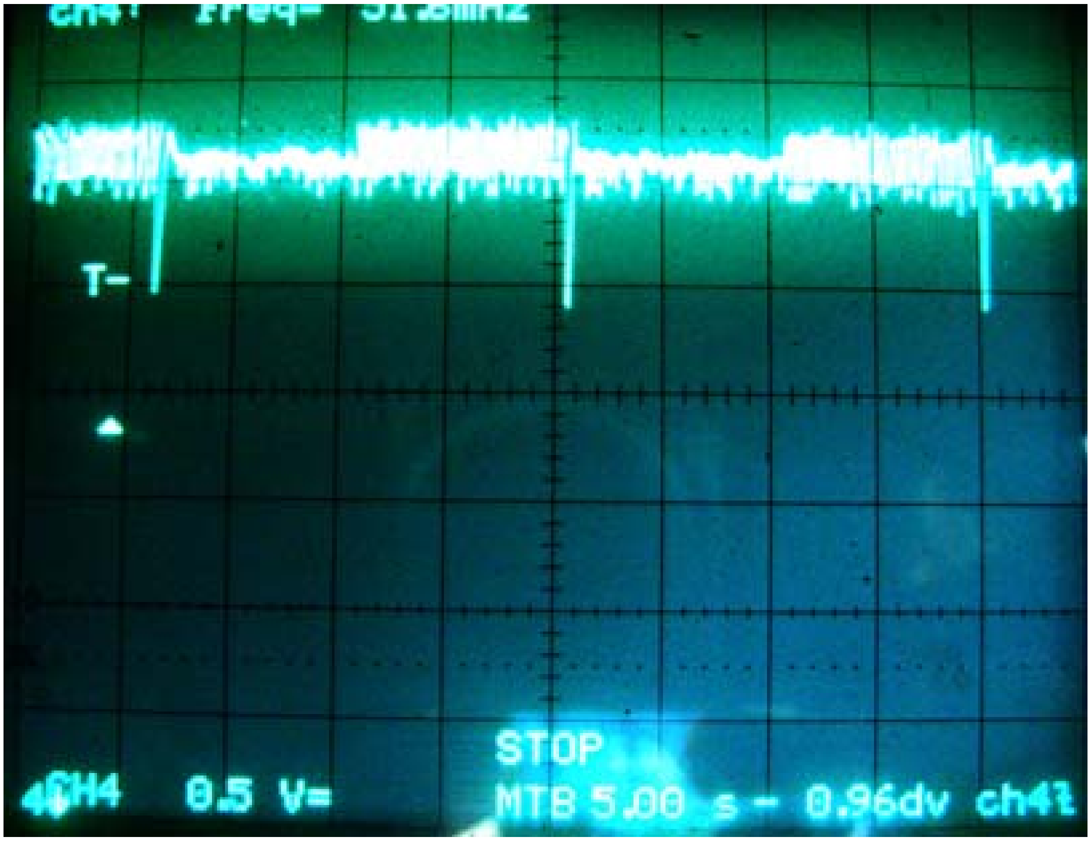
Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 10: Transient performance for 180 Watts at 500GPM.

6.10) 600GPM, Full Load Open & Closed loop.

Fig 11 illustrates the performance of the alternator at 600GPM subjected to the same simple series of 90 Watt drop tests and again the alternator was able to maintain a regulated 30V output and a 90 Watts load. The alternator's regulation profile can be seen to be flat with an excellent demonstration of transient dynamics under these arduous test conditions.

Conclusion: 600GPM can support 90 Watts in regulation.



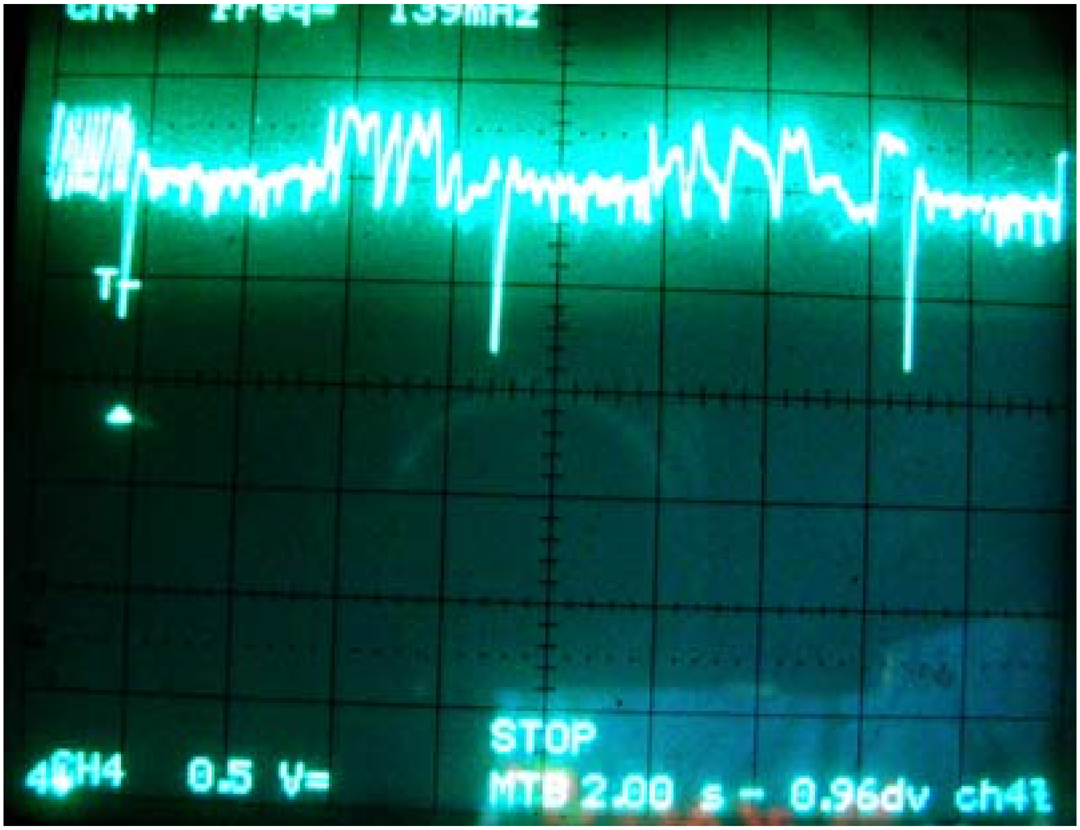
Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 11: Transient performance for 90 Watts at 600GPM.

6.11) 600GPM, Twice full Load Open & Closed loop.

Fig 12 illustrates the performance of the alternator at 600GPM subjected to a twice full load drop test of 180 Watts. Despite this enormous over load condition, this plot proved the alternator was able to maintain a regulated output of 30V at 600GPM and still maintained excellent transient dynamics. Note that this plot also suffered some aliasing distortion in the loaded state.

Conclusion: 600GPM can support 180 Watts in regulation.



Horizontal scale = 2s per div. Vertical scale = 5V per div.

Fig 12: Transient performance for 180 Watts at 600GPM.

7.0) Report Conclusions.

All mud alternators extract their power from mud flow through the turbine blades of the impeller. Output power is therefore inextricably linked to flow rate; the higher the flow rate, the greater the power that can be extracted from the mud. However, the output voltage of conventional open loop mud alternators also respond directly to flow rate and pass the high voltage stress of a high flow environment to the down stream electronic regulator causing it very high thermal stress and sometimes, premature failure. Once the electronic regulator fails, the entire down hole steering or surveying service fails which is a costly and commercially damaging service interrupt.

The purpose of the PolyComm closed loop alternator was to remove the open loop relationship between flow rate and output voltage by controlling the alternator's rotor and therefore limit and regulate the output voltage to some predetermined level; typically 30V for compatibility with existing battery stacks. However, closing the loop around the alternator also meant addressing the two potential problems of unconditional stability and dynamic stability which only closed loop systems can suffer from.

The evidence presented by this document proves that all three design goals have been achieved and within a very small package compared to competitive machines. The machine has been proven to provide a regulated output of 90 Watts at 30V for all flow rates above 400GPM and 180 Watts at 30V at 600GPM. Higher output power was possible had the output voltage been selected to be 33V or 35V and although this assertion was not tested, the open loop output power plots prove this statement to be true. See Flow_Loop_Regulation_Test_Report_260808.doc for more details.

When operating closed loop, the oscilloscope images showed very little disturbance to the regulated 30V output when full load was applied, confirming the machine was operating with a very low dynamic output resistance. Spreadsheet data, not reproduced in this report, have confirmed this figure to be less than one Ohm, making this 100 Watt alternator design suitable for the next generation of powerful EM Telemetry, steering, surveying and actuation tools.

Report End: 26th August 2008.