Turbine Dynamics

Down Hole Power and EM Telemetry

"Performance beyond Expectation"

Unit D, Asquith Court, Saxon Business Park, Stoke Prior, Worcestershire. B60 4FF. Tel: (044) 1527 759160
www.turbinedynamics.com

Turbine alternator flow loop test report.

Document Created 20th August 2008.
Revision 2.
Last Modified 22nd February 2017.
Author: Greg Spring, Turbine Dynamics Ltd.

1.0) Introduction.

There are two types of independent electrical power source used for all down hole MWD/LWD instrumentation, batteries and alternators/generators. Wireline has been eliminated from this discussion because it derives its power from the surface and is therefore not an independent power source. Batteries sub divide into low temperature alkaline and high temperature Lithium ion and continue to serve the drilling industry very well. However, whilst batteries offer a very cost effective solution for low power instrumentation, their inherent limitations quickly surface when high power demands in combination with high temperature is needed. High powered battery stacks also become very lengthy liabilities on the Cat Walk due to the magnitude of their stored energy and therefore pose a significant threat for explosion and/or fire. Service companies have to implement various fail safe measures to ensure their battery operated equipment does not accidentally become live at the Well Head because of this potential danger. Lithium ion batteries can also explode if subjected to excessive shock, e.g. dropped or subjected to sustained vibration, doubling their hazard at the point of entry on the rig site. Taking into account their initial cost, length, weight, limited power and down hole life, high temperature leakage and final disposal costs, Lithium battery stacks become a costly and inefficient choice of primary power for demanding MWD/LWD applications.

Mud alternators, otherwise known in the industry as mud turbines or mud generators do not suffer from any of these problems being electrically inert when handled on the rig surface and only generate significant levels of power when safely disposed down hole. For high power applications they are more volumetrically efficient than battery stacks and for all practical purposes have an unlimited energy capacity (Watt.Hours) when compared to batteries. These features make alternators a more practical power source than batteries for high temperature, high power down hole applications like EM Telemetry which can deliver a fast and continuous stream of steering and surveying data regardless of the hydraulic conditions down hole. However, EM Telemetry frequently fails to live up to this promise due to the limitations imposed by the batteries used to power these tools. Considering an average bit run is 350+ hours, batteries are simply not a good fit for EMT or any other high power MWD/LWD application and therefore the only other realistic power source is a mud alternator.

2.0) Open or Closed Loop

Until Turbine Dynamics successfully designed the World's first closed loop alternator, all down hole mud alternators were by definition, open loop. This meant that the raw rectified output voltage from the alternator was dependent upon the mud flow rate through the impeller blades. The faster the mud flow, the faster the impeller turned and the higher the alternator's output voltage. In an ideal instrumentation string, all the tools in that string would be arranged to work with a common and optimum flow rate. However, this ideal assembly is sometimes not possible and one or more tools are therefore forced to run with sub optimal flow rate. This can lead to either under performance if the flow rate is too low or excessive erosion if the flow rate is too high. Optimal flow conditions for the entire instrumentation string is therefore not always possible and a tool which can automatically adjust itself to compensate for sub optimal flow would bring commercial benefit to the Service Companies operating them and practical benefit for their field engineers.

To some extent turbine manufacturers have minimised the problem of sub optimal flow by shipping several different blade profiles with each mud alternator so that they can be matched to the prevailing on site flow conditions. Although this tactic has been successful over the years, it carries with it greater overhead costs in the form of design, inventory, transportation and general management costs and has therefore been a necessary but inefficient expedient to overcome a fundamental disadvantage of using conventional open loop mud alternators. This tactic also fails to overcome the influence of human error which is known the thwart even the best laid drilling plans.

A much more serious operational consequence of using a free running open loop alternator is the high voltage stress they cause to down hole, down stream electronic instrumentation. Open loop alternators are post processed by an electronic switch mode power supply to convert the alternator's raw DC to one or more regulated supplies suitable for down hole instrumentation; usually +5V (+3V3) for processors and other logic and ±12V for analogue circuits. Spinning at very high rpm, some extant open loop alternators generate up to 150V DC which adds significant voltage stress to the switch mode power supply. This in turn, causes significant internal heating and in a 150ºC environment, the heat loss can raise the die temperature of the electronics well above 175ºC, reducing conversion efficiency, power transfer and reliability. High voltage stress at high ambient temperature is therefore the most common cause for switch mode power supply failure, so by eliminating the high voltage stress at source, the long term reliability and efficiency of all down stream MWD/LWD electronics is improved.

3.0) The Closed Loop Alternator

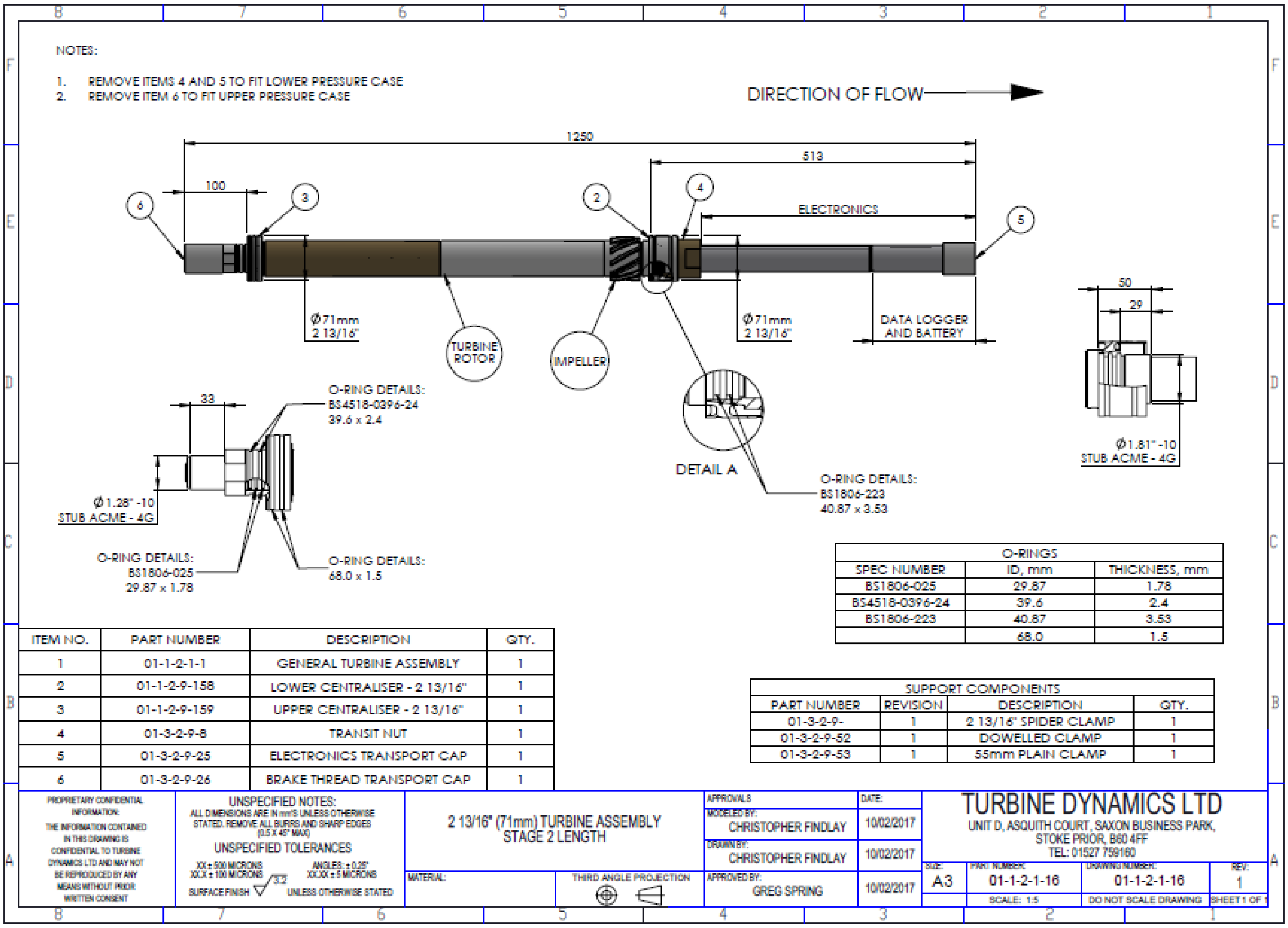
The Turbine Dynamics closed loop alternator is the World's first machine to solve this problem by breaking the link between flow rate and output voltage. For the first time, the raw rectified alternator output is available directly as a high power regulated voltage source enabling much more ambitious drilling instrumentation to be planned without any loss to the flexibility and convenience of this type of machine. Although these test results were taken at 30V, the machine is easily programmed for any output voltage and is therefore a customer configurable variable. The choice of 30V for these tests was to highlight the fact that this machine could easily replace or complement existing 30V Lithium Ion battery stacks without affecting the design of the extant drilling steering and/or surveying instrumentation. The advantages of closed loop control over open loop alternators can be summarised in the following table:

Statement	Open Loop	Closed Loop	Comments
Mechanical			
Flow Rate Dependent	Yes	No	Open loop cannot protect itself against changing flow conditions
Automatic Flow Density Compensation	No	Yes	Open loop cannot defeat changes in mud density, e.g. under balanced drilling fluid.
Excessive RPM	Yes	No	
Tool Length	Slightly Shorter	Slightly Longer	
Impellers	Many	One	Open loop optimisation means carrying several impellers to suit each job. Closed loop = One.
Optimum Flow Range	Narrow	Wide	Closed loop expands the operating range of any tool. Open loop relies on specific impellers for each job.
Repeatability	Average	Excellent	Closed loop guarantees repeatability of machines by minimising the effects of manufacturing tolerance and component errors.
Bearing Life	Good	Excellent	Closed loop optimises rotor speed and minimises bearing losses.
Impeller Life	Good	Excellent	Closed loop optimises rotor speed and minimises impeller erosion.
Electrical			
Excessive output voltage	Yes	No	
Output Resistance	Medium	Very Low	Open Loop R depends upon the design of the alternator. Closed loop significantly reduces output R for any machine.
100 Watt 175C variant	Difficult	Easy	Less dependency on electronics means higher power, higher temperature machines are easier to design and manufacture.
100 Watt 200C variant	Very Difficult	Possible	Both open and closed loop design routes limited by 200C silicon, but closed loop still easier to achieve.
Load Regulation	Acceptable	Excellent	Open loop load regulation is dependant upon the quality of the design. Closed loop regulation is always excellent.
Electronic Post Regulation	Yes	Optional	Open loop electronic regulation is a necessity, not an option. Closed loop electronic regulation is optional.
Switchable OL/CL	No	Yes	If required, closed loop control can be switched off.

4.0) Tool Dimensions and Flow Loop Conditions.

The 100 Watt closed loop alternator used for these tests was 55mm OD x 1600mm long and fitted with a 76mm OD impeller, designed for a 3” ID collar. The alternator was flow tested with a low, medium and high flow impeller at normal temperature and atmospheric pressure using a water glycol mix from 200GPM – 600GPM. A 1000uF, 200V reservoir capacitor was used to smooth the rectified 30V DC regulated output.

5.0) Engineering Drawing of the closed loop alternator used for these tests.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	01-1-2-1-1	GENERAL TURBINE ASSEMBLY	1
2	01-1-2-9-158	LOWER CENTRALISER - 2 13/16"	1
3	01-1-2-9-159	UPPER CENTRALISER - 2 13/16"	1
4	01-3-2-9-8	TRANSIT NUT	1
5	01-3-2-9-25	ELECTRONICS TRANSPORT CAP	1
6	01-3-2-9-26	BRAKE THREAD TRANSPORT CAP	1

O-RINGS		
SPEC NUMBER	ID, mm	THICKNESS, mm
BS1806-025	29.87	1.78
BS4518-0396-24	39.6	2.4
BS1806-223	40.87	3.53
	68.0	1.5

SUPPORT COMPONENTS			
PART NUMBER	REVISION	DESCRIPTION	QTY.
01-3-2-9-	1	2 13/16" SPIDER CLAMP	1
01-3-2-9-52	1	DOWELLED CLAMP	1
01-3-2-9-53	1	55mm PLAIN CLAMP	1

PROPRIETARY CONFIDENTIAL INFORMATION: THE INFORMATION CONTAINED IN THIS DRAWING IS CONFIDENTIAL TO TURBINE DYNAMICS LTD AND MAY NOT BE REPRODUCED BY ANY MEANS WITHOUT PRIOR WRITTEN CONSENT

UNSPECIFIED NOTES:
ALL DIMENSIONS ARE IN mm'S UNLESS OTHERWISE STATED. REMOVE ALL BURRS AND SHARP EDGES (0.5 X 45° MAX)

UNSPECIFIED TOLERANCES
XX ± 500 MICRONS
XX.X ± 100 MICRONS
ANGLES: ± 0.25°
XX.XX ± 5 MICRONS
SURFACE FINISH 3.2 UNLESS OTHERWISE STATED

2 13/16" (71mm) TURBINE ASSEMBLY
STAGE 2 LENGTH

MATERIAL:
THIRD ANGLE PROJECTION

APPROVALS	DATE:
MODELED BY: CHRISTOPHER FINDLAY	10/02/2017
DRAWN BY: CHRISTOPHER FINDLAY	10/02/2017
APPROVED BY: GREG SPRING	10/02/2017

TURBINE DYNAMICS LTD
UNIT D, ASQUITH COURT, SAXON BUSINESS PARK,
STOKE PRIOR, B60 4FF
TEL: 01527 759160

SIZE:	PART NUMBER:	DRAWING NUMBER:	REV:
A3	01-1-2-1-16	01-1-2-1-16	1
	SCALE: 1:5	DO NOT SCALE DRAWING	SHEET 1 OF 1

Fig 1: An example of the closed loop alternator used for these tests.

6.0) Flow Loop Data.

The spreadsheet plots presented in this report prove that a closed loop mud alternator can maintain a regulated output within a flow range of 250GPM – 600GPM with only one, low flow impeller. This data proved that the traditional method of shipping two or more sets of flow gear with every tool to ensure it can match on site flow conditions is redundant, saving equipment and overhead costs for every tool and every job. The high, medium and low flow impellers used for these tests were cut with 20 degree, 25 degree and 30 degree blade profiles respectively. To illustrate the dramatic difference between open and closed loop control, each impeller was also tested open loop and these plots lead each discussion.

7.0) Open and Closed Loop Flow Data.

7.1) 20 Degree Impeller Open Loop Voltage.

Fig 2 illustrates the performance of the alternator fitted with a 20 degree impeller and configured as an open loop machine. The open loop rectified output voltage was recorded against flow rate for various step loads from open circuit to 5R as shown on the graph. This is a typical voltage verses speed response available from any open loop alternator where the precise voltage to speed characteristic is primarily determined by the impeller. Note that the rectified output voltage falls with load as would be expected from any machine of this type.

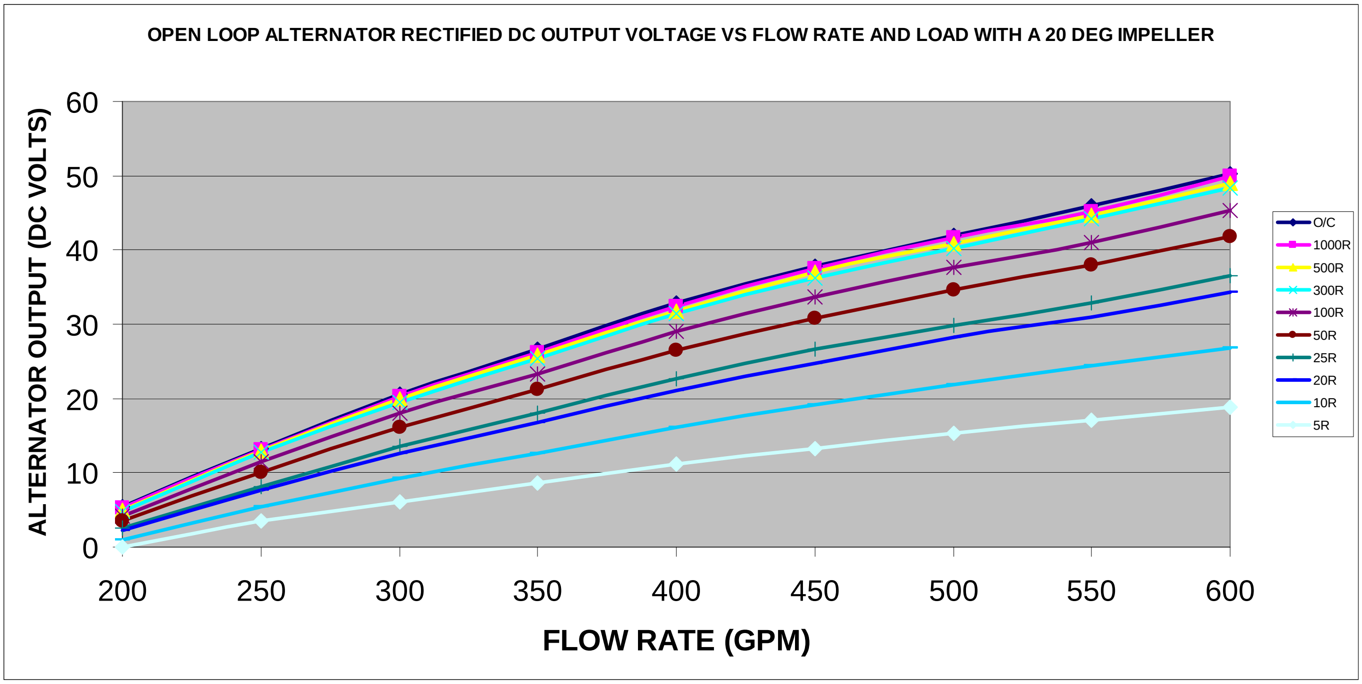


Fig 2: Open loop voltage vs flow rate & load with a 20 degree impeller.

7.2) 20 Degree Impeller Open Loop Power.

Fig 3 illustrates the open loop output power of the alternator fitted with a 20 degree impeller.

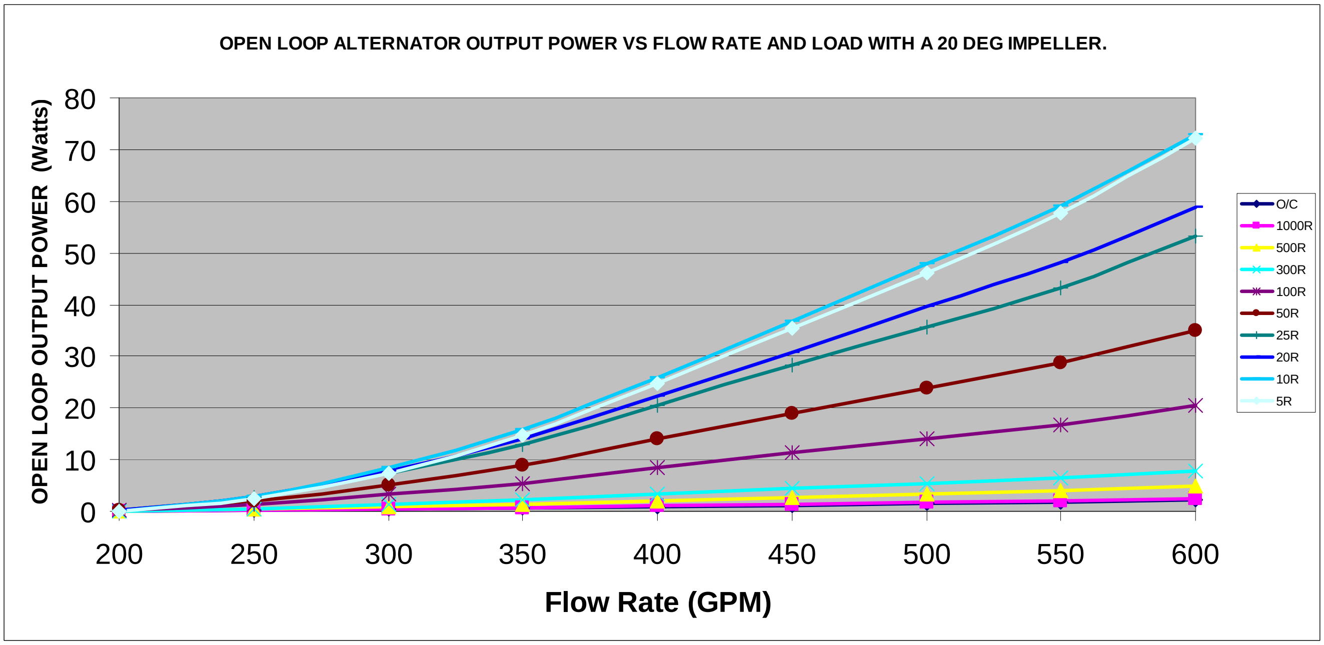


Fig 3: Open loop output power vs flow rate & load with a 20 degree impeller.

7.3) 20 Degree Impeller Closed Loop Voltage.

Fig 4 illustrates the performance of the alternator fitted with the same 20 degree impeller, but this time configured as a 30V regulated closed loop machine. The rectified output voltage was recorded against flow rate for various step loads from open circuit to 5R as shown on the graph. This data showed that the flow rate had to exceed 400GPM before 30V regulation could occur with a 20 deg impeller. Although suitable for the higher flow ranges, this impeller was not an optimal choice for the entire flow range of 200GPM – 600GPM.

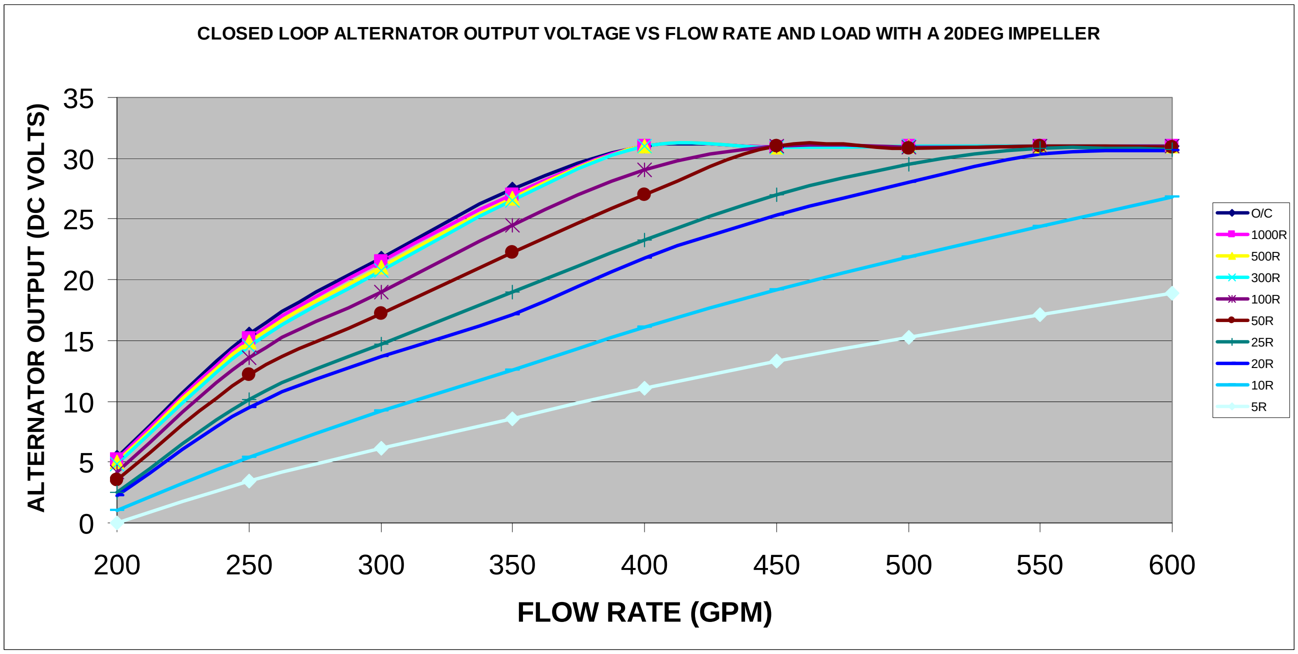


Fig 4: Closed loop voltage vs flow rate & load with a 20 degree impeller.

7.4) 20 Degree Impeller Closed Loop Output Power.

Fig 5 illustrates the relationship between output power and flow rate from the machine. As expected, alternator power increased with flow rate, but as will become evident from this and later graphs, closed loop control limits the maximum power available from the alternator making the machine much more predictable down hole where there is less control over actual flow rate. This can be interpreted as a useful safety feature for the protection of expensive MWD/LWD instrumentation systems. Note the flat power characteristic from open circuit to 20R was lost for 10R & 5R loads because the alternator couldn't generate 30V under these circumstances and therefore represent open loop power curves.

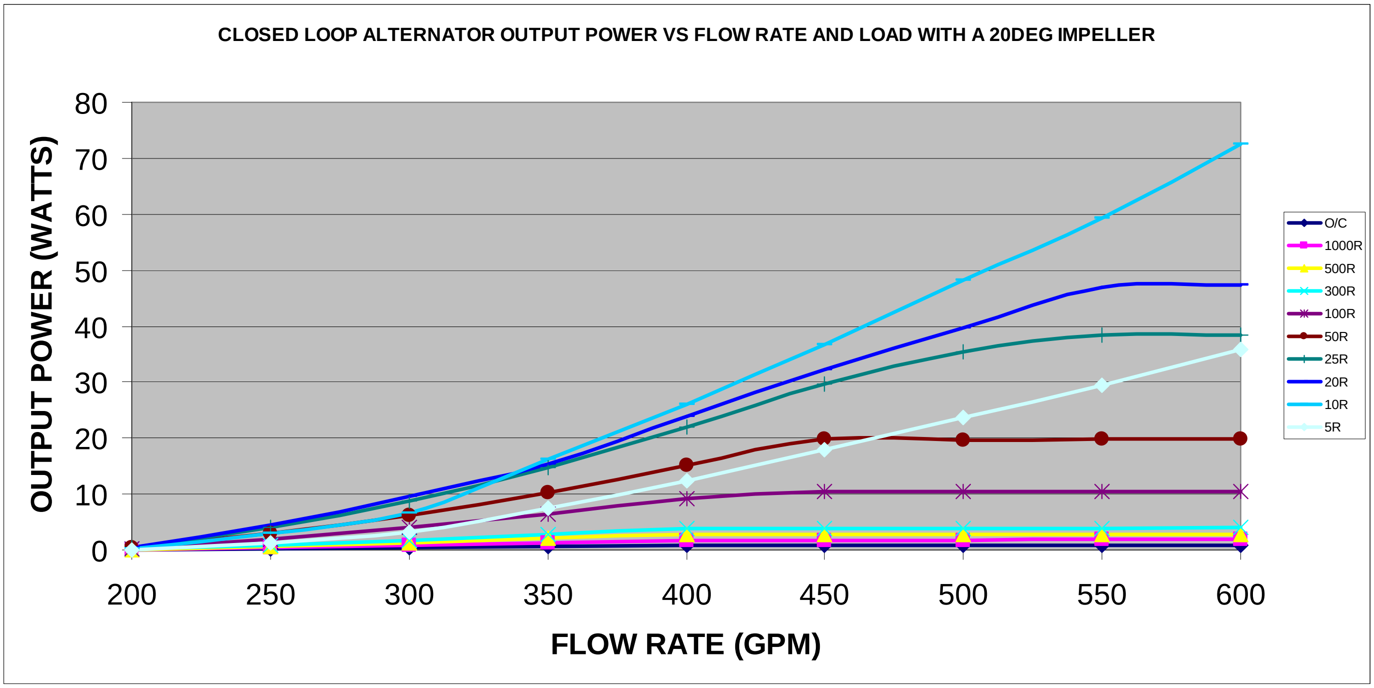


Fig 5: Closed loop output power vs flow rate & load with a 20 degree impeller.

7.5) 20 Degree Impeller Closed Loop Rotor Speed.

Fig 6 illustrates the change in rotor speed with flow rate and load. These plots illustrate how the machine constantly adjusted its rotor dynamics to maintain closed loop control and a constant output voltage against changes in flow rate and/or load. Note that with a 20 degree impeller, the machine behaviour was open loop below 400GPM and closed loop above 400GPM.

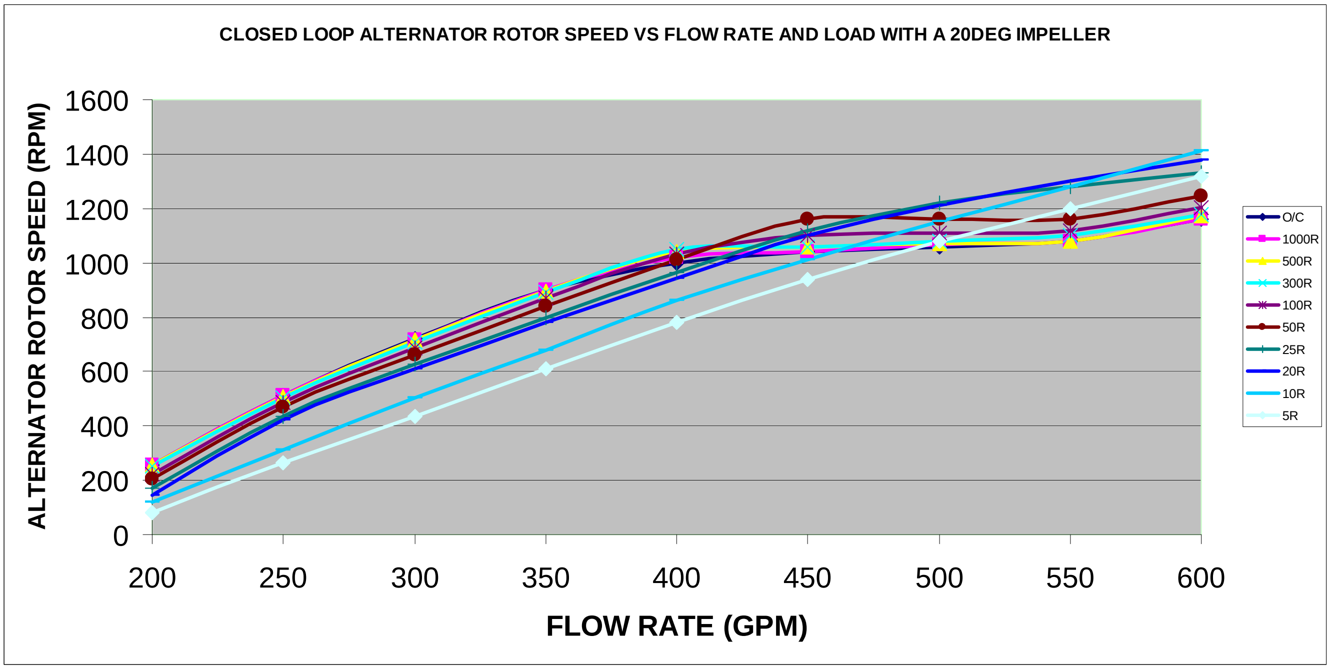


Fig 6: Closed loop rotor speed vs flow rate & load with a 20 deg impeller.

7.6) 25 Degree Impeller Open Loop Voltage.

Fig 7 illustrates the performance of the alternator fitted with a 25 degree impeller and configured as an open loop machine. The open loop rectified output voltage was recorded against flow rate for various step loads from open circuit to 5R as shown on the graph. This is a typical voltage verses speed response available from any open loop alternator where the precise voltage to speed characteristic is primarily determined by the impeller. Note that the rectified output voltage falls with load as would be expected from any machine of this type.

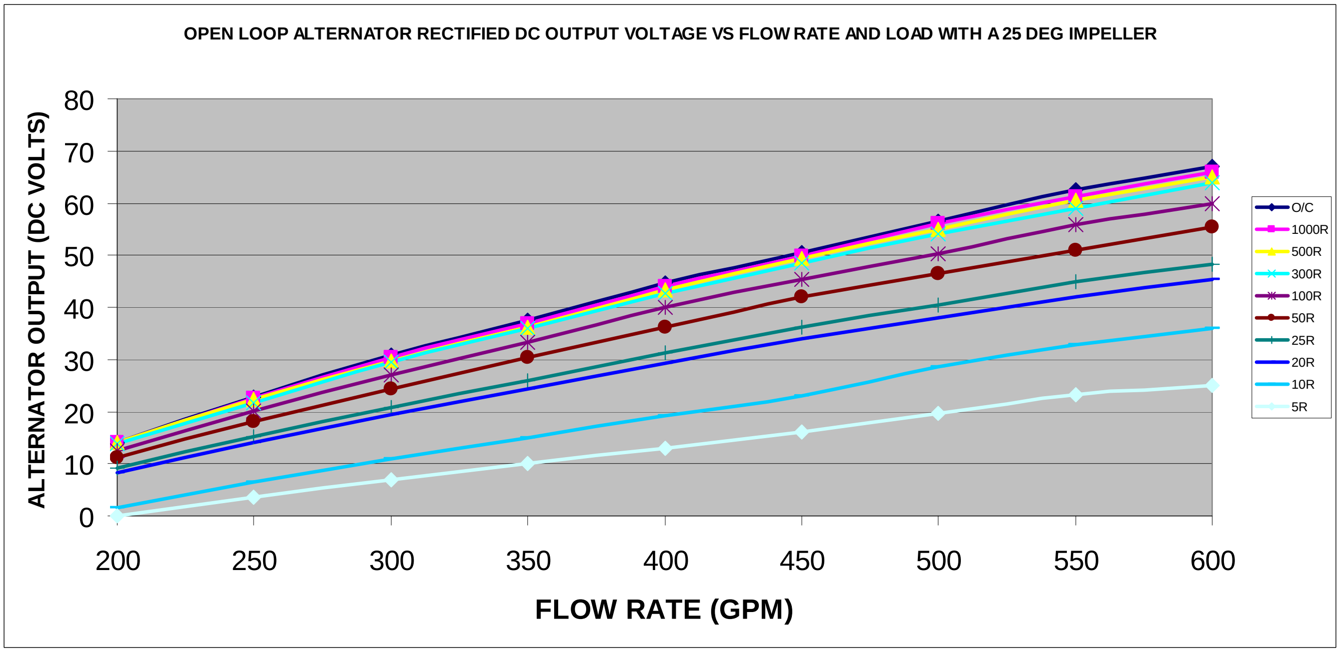


Fig 7: Open loop voltage vs flow rate & load with a 25 degree impeller.

7.7) 25 Degree Impeller Open Loop Power.

Fig 8 illustrates the open loop output power of the alternator fitted with a 25 degree impeller.

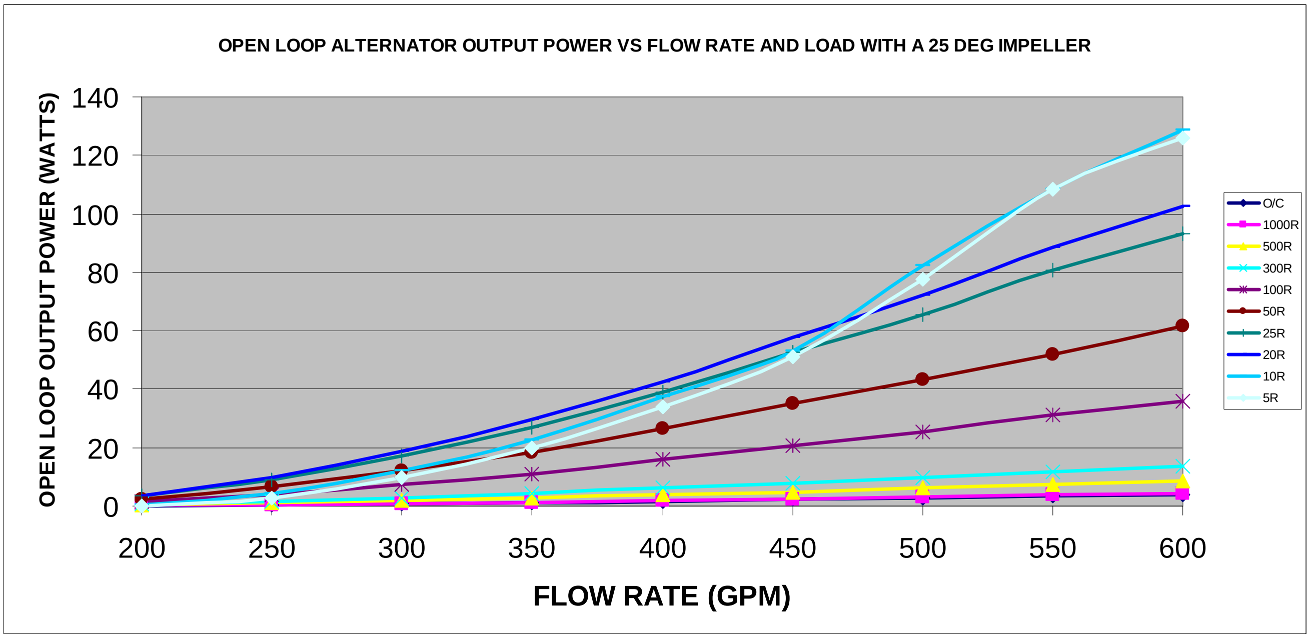


Fig 8: Open loop output power vs flow rate & load with a 25 degree impeller.

7.8) 25 Degree Impeller Closed Loop Voltage.

Fig 9 illustrates the performance of the alternator fitted with the same 25 degree impeller configured as a 30V regulated closed loop machine. The rectified output voltage was recorded against flow rate for various step loads from open circuit to 5R as shown on the graph. This data showed that with a 25 deg impeller, the flow rate to achieve 30V regulation fell to only 300GPM compared to 400GPM for the 20 deg impeller. Although suitable for the medium flow ranges, this impeller was still not an optimal choice for the entire flow range of 200GPM – 600GPM.

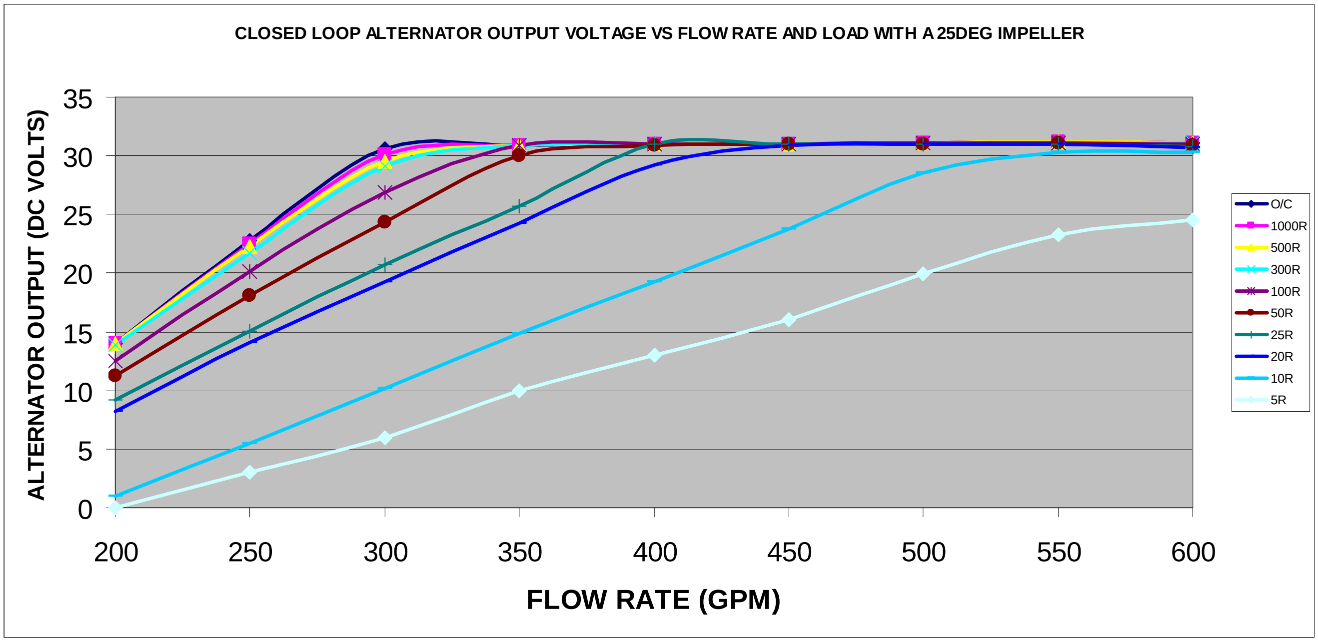


Fig 9: Closed Loop Voltage vs flow rate & load with a 25 degree impeller.

7.9) 25 Degree Impeller Closed Loop Output Power.

Fig 10 illustrates the relationship between output power and flow rate from the machine. As expected, output alternator power increased with flow rate, but this graph also confirmed that closed loop control limits the maximum power available from the alternator creating a safer power delivery system for MWD/LWD instrumentation systems.

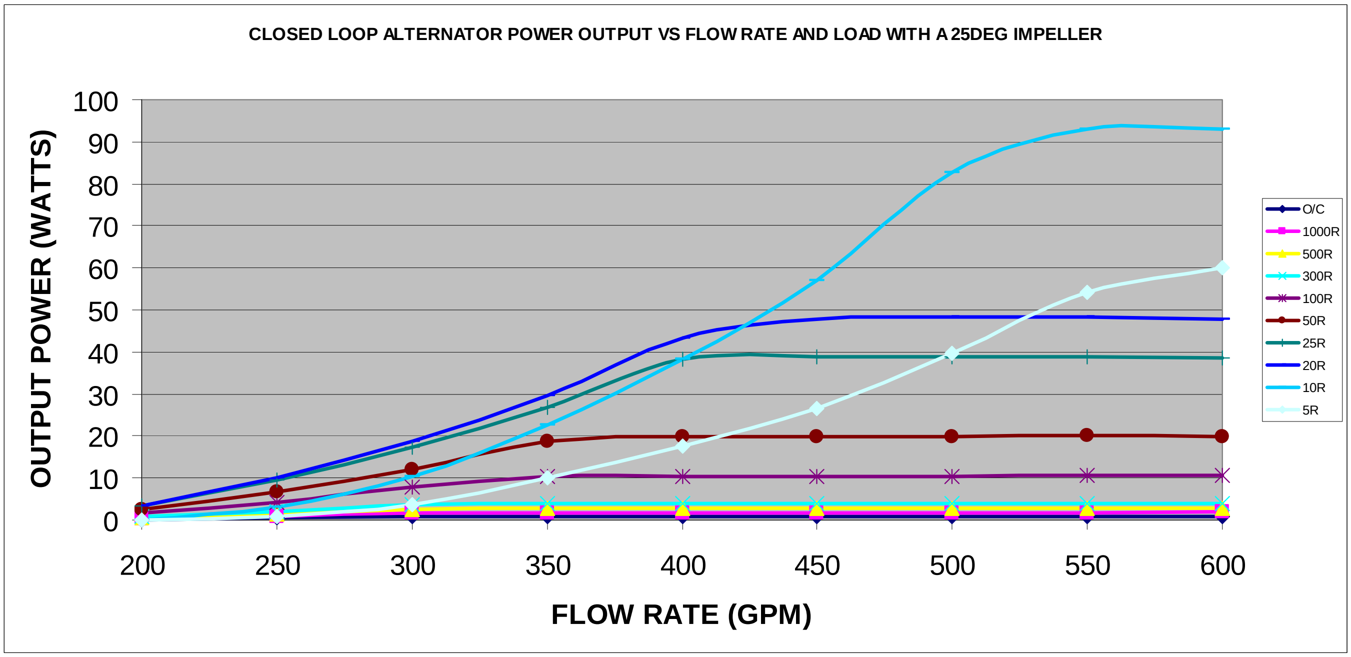


Fig 10: Closed loop output power vs flow rate & load with a 25 degree impeller.

7.10) 25 Degree Impeller Closed Loop Rotor Speed.

Fig 11 illustrates the change in rotor speed with flow rate and load. By maintaining closed loop control of rotor above 300GPM, the machine constantly adjusted its rotor dynamics to maintain a regulated 30V output voltage regardless of changes to flow rate or load.

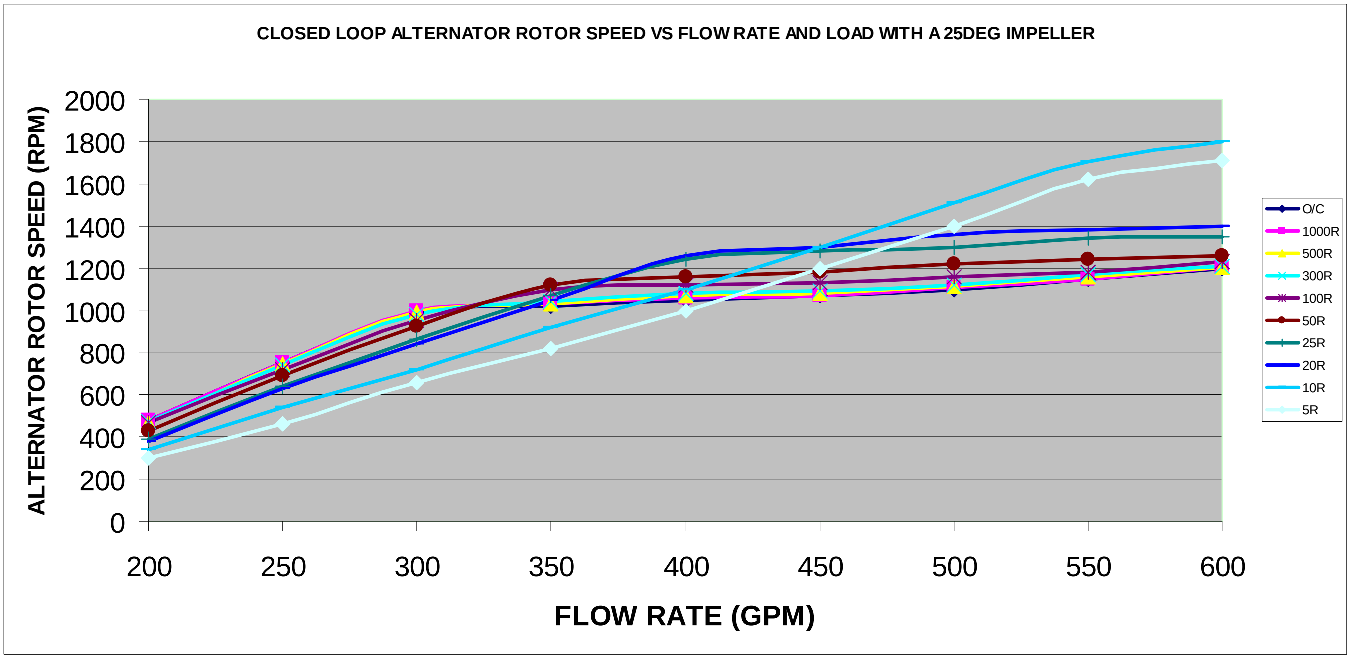


Fig 11: Closed loop rotor speed vs flow rate & load with a 25 deg impeller.

7.11) 30 Degree Impeller Open Loop Voltage.

Fig 12 illustrates the performance of the alternator fitted with a 30 degree impeller and configured as an open loop machine. The open loop rectified output voltage was recorded against flow rate for various step loads from open circuit to 5R as shown on the graph. This is a typical voltage verses speed response available from any open loop alternator where the precise voltage to speed characteristic is primarily determined by the impeller. Note that the rectified output voltage falls with load as would be expected from any machine of this type. This graph read in combination with Fig 13 illustrates the disadvantages of open loop mud alternators more than any of the previous graphs. Fitted with a low flow, 30 degree impeller, the open loop rectified output voltage swings between 6V and 90V depending upon flow rate and load. A switch mode power supply fitted to this alternator would therefore have to convert this entire voltage spread into much lower instrumentation voltages safely and efficiently and at high temperature. Whilst this can be achieved optimally for low voltage inputs, e.g. 30V – 40V, 220GPM – 300GPM, the series switch mode power supply becomes less efficient for higher input voltages caused by higher flow rates. It is unrealistic and impractical to insist the drilling engineer restricts flow rate to such low levels simply to satisfy the particular demands of the switch mode power supply, therefore the only other solution is to limit the rectified output over the entire flow range which is what the closed loop alternator has succeeded in doing.

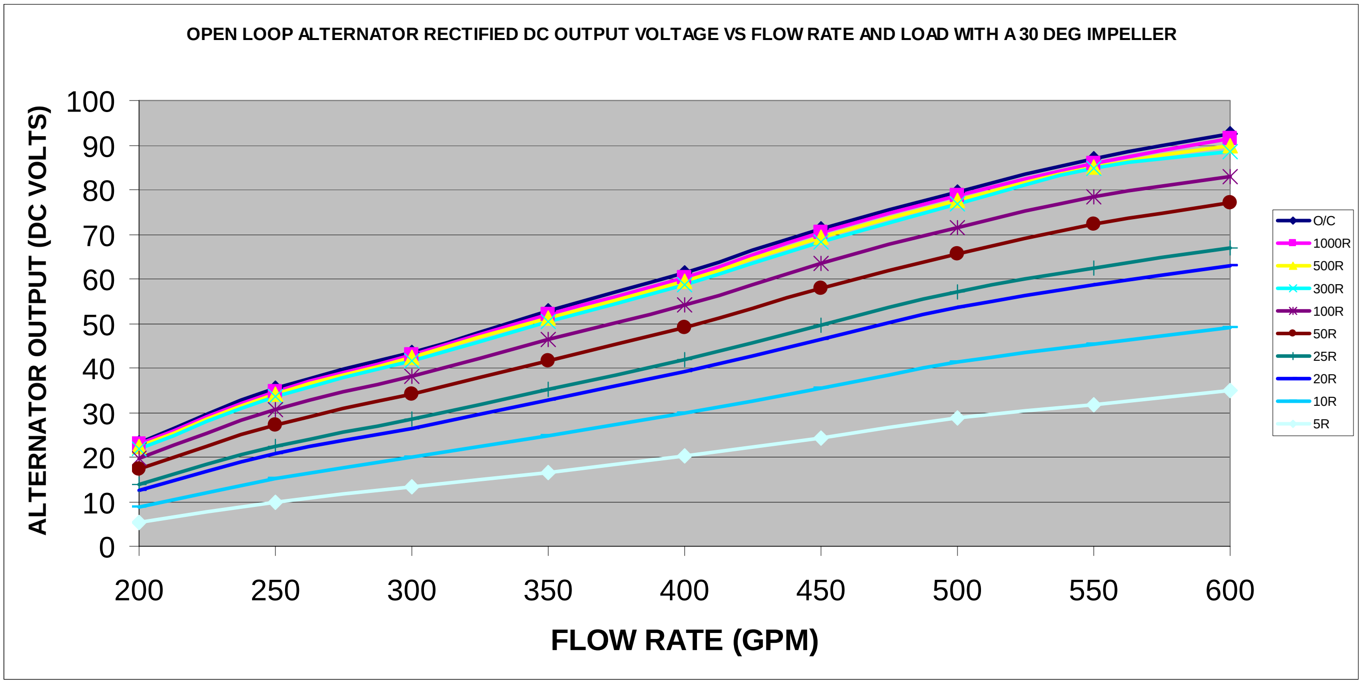


Fig 12: Open loop voltage vs flow rate & load with a 30 degree impeller.

7.12) 30 Degree Impeller Open Loop Power.

Fig 13 illustrates the open loop output power of the alternator fitted with a 30 degree impeller. Whilst this graph illustrates the full open loop potential of the alternator, there is no control over the power delivered to the load as illustrated by Fig 15. Using the alternator in closed loop not only controls the output voltage, but indirectly limits the maximum power available to the load.

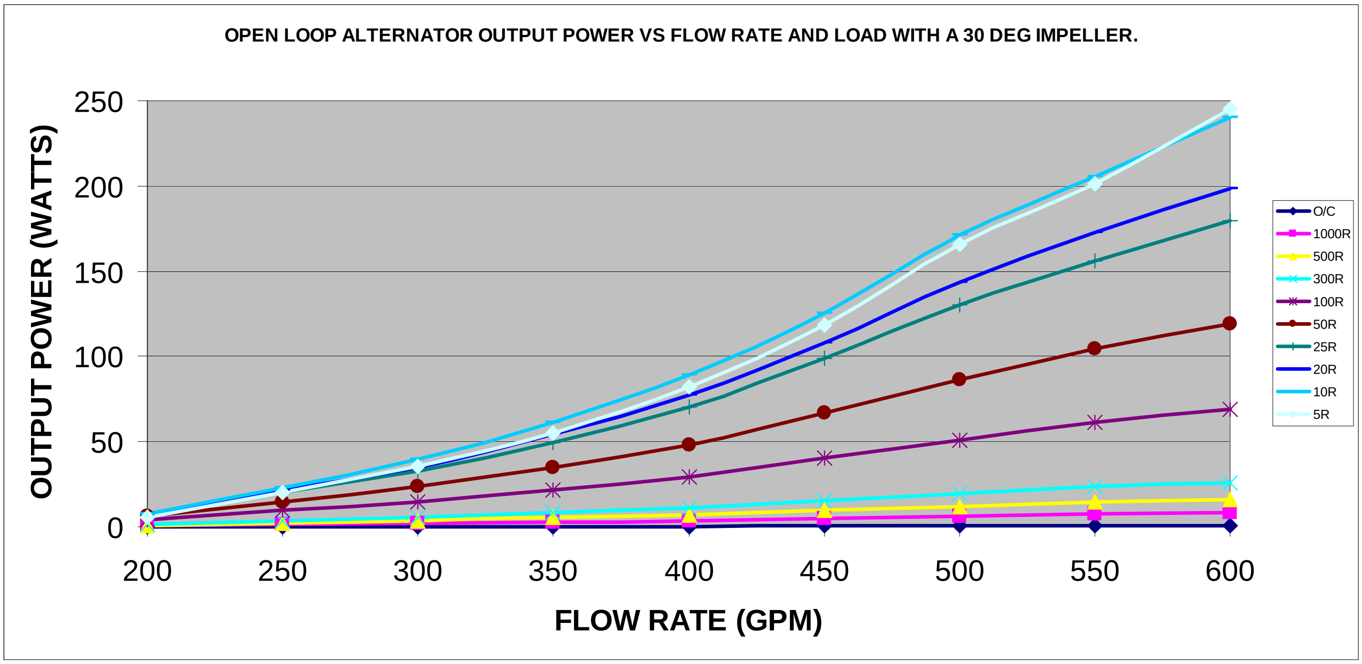


Fig 13: Open loop output power vs flow rate & load with a 30 degree impeller.

7.13) 30 Degree Impeller Closed Loop Voltage.

Fig 14 illustrates the performance of the alternator fitted with the same 30 degree impeller configured as a 30V regulated closed loop machine. The rectified output voltage was recorded against flow rate for various step loads from open circuit to 5R as shown on the graph. This data showed that the flow rate only had to exceed 250GPM before 30V regulation could occur with this impeller. Normally only suitable for the low flow ranges, this graph proved that a closed loop alternator could work with this impeller over the entire flow range of 200GPM – 600GPM obviating the need for any other impellers to match higher flow rates as is required for conventional open loop machines.

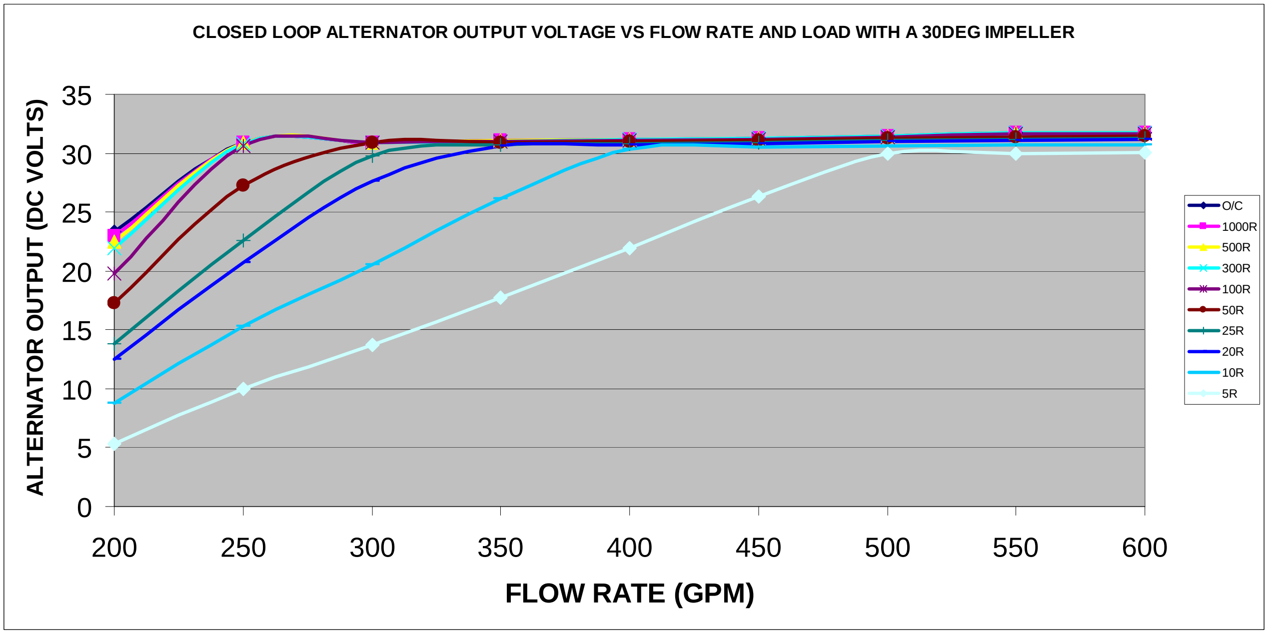


Fig 14: Closed Loop Voltage vs flow rate & load with a 30 degree impeller.

7.14) 30 Degree Impeller Closed Loop Output Power.

Fig 15 illustrates the relationship between output power and flow rate from the machine. As expected, output alternator power increased with flow rate, but closed loop control limits the maximum power available from the alternator creating a safer power delivery system for MWD/LWD instrumentation systems.

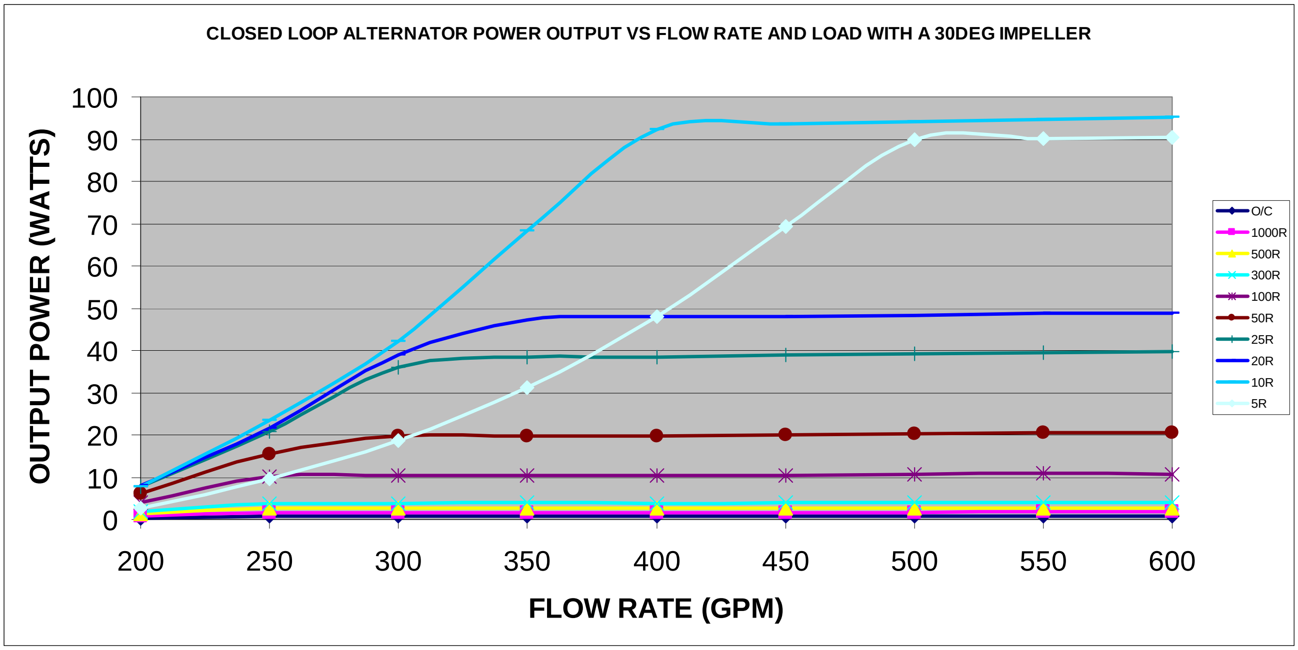


Fig 15: Closed loop output power vs flow rate & load with a 30 degree impeller.

7.15) 30 Degree Impeller Closed Loop Rotor Speed.

Fig 16 illustrates the change in rotor speed with flow rate and load. By maintaining closed loop control of rotor above 250GPM, the machine constantly adjusted its rotor characteristics to maintain a regulated 30V output voltage regardless of changes to flow rate or load.

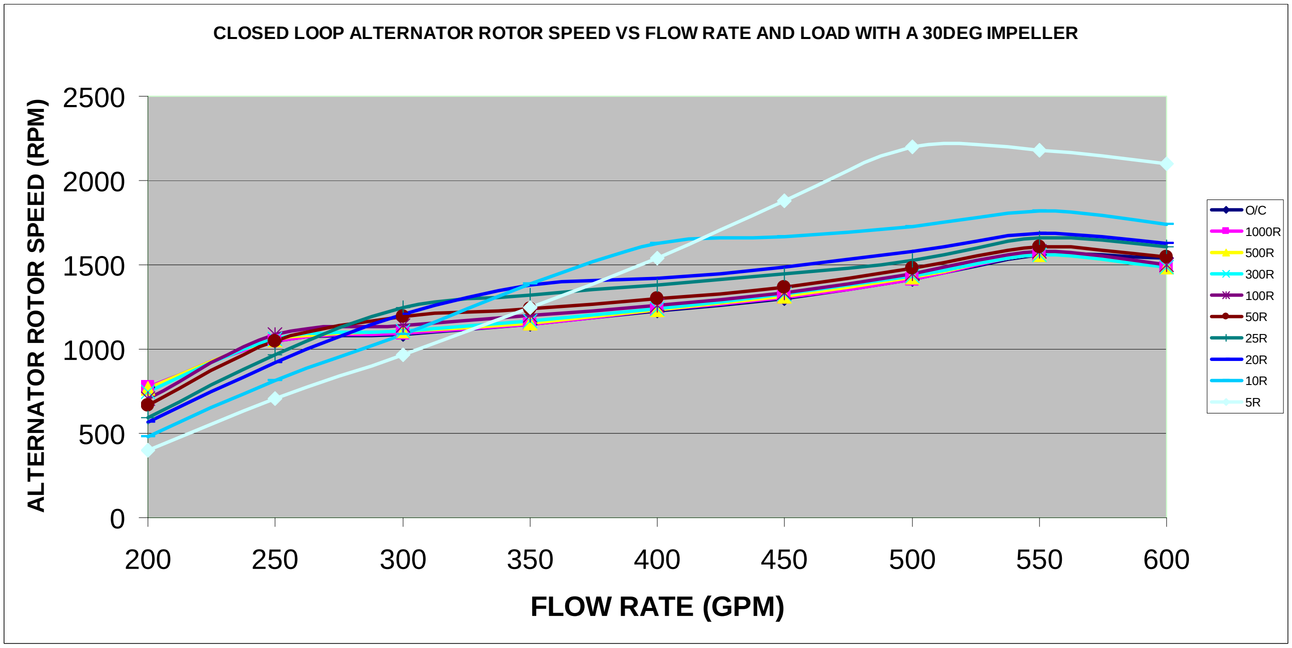


Fig 16: Closed loop rotor speed vs flow rate & load with a 30 deg impeller.

8.0) Conclusions.

All mud alternators develop an output voltage and extract their power from mud flow through the blades of their impeller. Alternator output voltage and power is therefore inextricably linked to flow rate; the higher the flow rate, the greater the voltage and power that can be extracted from the mud. A conventional open loop mud alternator responds directly to flow rate and passes the high voltage and hence the high thermal stress of a high flow condition to the down stream electronic regulator. In some cases, the combination of these extremes leads to failure of the down stream electronics and potential failure of the down hole steering, surveying or other instrumentation service.

It is well known that high down hole temperature affects the resistance of copper based instruments and changes their characteristics. Local feedback and other forms of temperature compensation in these instruments minimises the disturbing effects of high temperature and by using the same principles, feedback wrapped around an alternator minimises the disturbing effect of down hole temperature, changes in flow rate, mud density, output load and wear and tear to the machine caused by flow erosion. Although no erosion tests have been conducted to date to prove this assertion, its truth is implied by the three sets of impeller data presented in this report. In all three cases, the closed loop alternator was able to automatically compensate for coarse changes in impeller blade angle and maintain a regulated 30V DC output once there was sufficient flow to maintain regulation under load.

One objective of the Turbine Dynamics closed loop alternator project was to remove the open loop relationship between flow rate and output voltage by controlling the alternator's rotor speed and therefore limit and regulate the rectified output voltage to some predetermined level; typically 30V for compatibility with existing battery stacks and MWD/LWD instrumentation. Another objective was to demonstrate that under closed loop control, a mud alternator would become a down hole, self regulating machine capable of automatically compensating for changes in flow rate, output load and machine characteristics. The data presented by this report proved that both of the first two objectives were achieved and the third objective is claimed by the use of alternate impellers to simulate worst case erosion applied to the low flow blade profile. Final proof will be available once the design has been subjected to flow loop erosion tests and field trials.

Report End: 26th August 2008.