PRO-TIDE

Power measurements
on the
W2E Vertical Axis Water Turbine

MTI-Holland,

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Dr. ir. J. van Berkel

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Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

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DIV240

Power measurements on the W2E Vertical Axis Water Turbine

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Power measurements on the W2E Vertical Axis Water Turbine

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10-8-2015	DIV240	V1.1	Final	R. Stam

Client	Provincie Zeeland / Pro-Tide
Reference number	15008406
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Quality control

This report has been reviewed and approved in accordance with the policies of MTI Holland B.V.

	Name	Date	Signature
Composed	R. Stam	10-8-2015	
Reviewed	P.Fremouw	12-8-2015	
Approved	R.A.P. Higler	12-8-2015	

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This document is dated 10-8-2015

Summary

On the request of Provincie Zeeland / Pro-Tide measurements were taken on the Vertical Axis Water Turbine of Water2Energy B.V. by MTI Holland, dept. Measuring & Diagnostics. Measurements were carried out on June 5- 9, 2015, near the weir complex at Amerongen.
On and around the turbine the following parameters are measured: turbine shaft torque and speed, flow through the turbine and pressure difference over the turbine. The measurements will be analysed in detail by Pro-Tide and the supplier of the turbine, W2E, for this purpose the raw data is provided. However some characteristic plots are already made and presented in this report.

Table of contents

1 Introduction

On the request of Provincie Zeeland / Pro-Tide measurements were taken on the Vertical Axis Water Turbine of Water2Energy (W2E) B.V. by MTI Holland, dept. Measuring & Diagnostics. Measurements were carried out on June 5- 9, 2015, near the weir complex at Amerongen.

2 Measuring apparatus and measuring methods

On and around the turbine the following parameters are measured: turbine shaft torque and speed, flow through the turbine and pressure difference over the turbine. All signals were logged using a data acquisition device make Dewesoft, type DEWE43, with a sample frequency of 100Hz. A figure of the complete test setup including measuring locations is shown in figure 1.

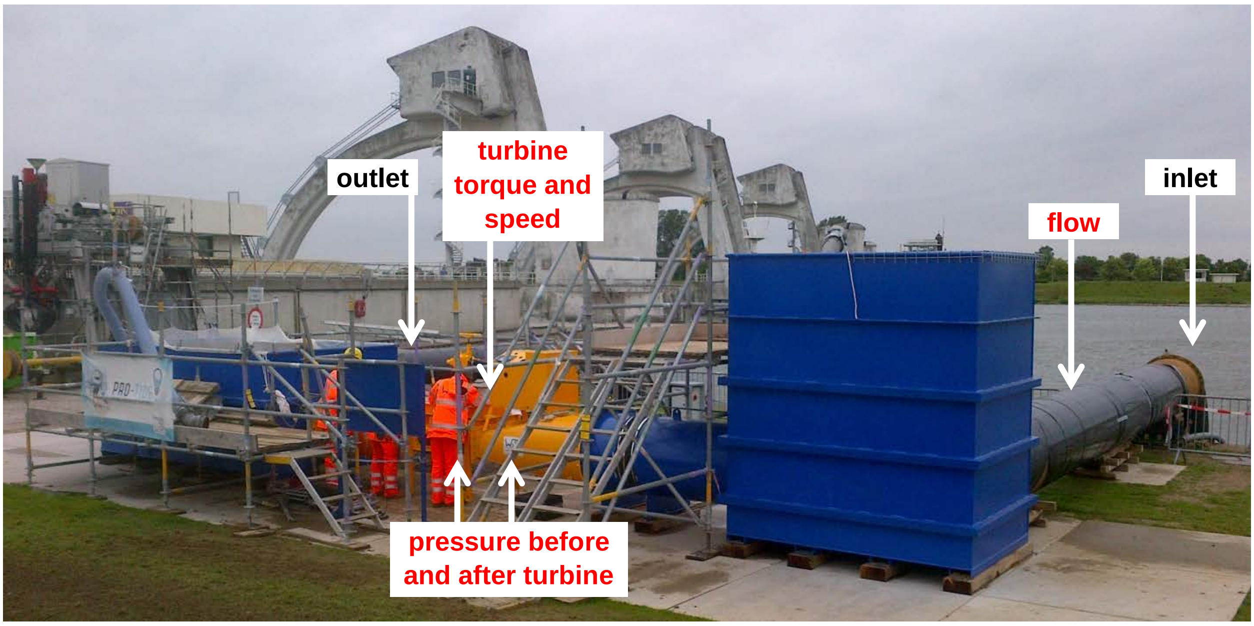

Figure 1: Complete turbine test setup, measurement locations in red.

2.1 Torque and speed

A view of the turbine shaft as supplied by W2E, with the measurement location, is shown in figure 2. The torque in this shaft ($D_{out\text{-}ward}$ ∅ 45mm) was measured by means of strain gauges, make HBM, with a resistance of 350 ohm and a k-factor of 2.04. By means of frequency modulated torque meter, fitted on the measured shaft, the strain gauge signals were recorded, through transmitting and receiver equipment make Binsfeld. Calculation of torque in the shaft is based on the shear modulus G = $8.1939*10^{10}$N/m^2 of the shaft material. The calculation of the torque scale factor can be found in attachment A.

The conditions for an accurate (±2%) torque measurement using strain gauges are:

- Well known shear module of the shaft material
- > 1.5 * diameter undisturbed shaft length
- > 30um/m torsional strain

In this case the torsional strain was critical. Only at maximum power the torsional strain meets this criterion: 1620W at 148rpm gives 36µm/m. Therefore the inaccuracy of torque measurement in general, is more than ±2%.

W2E estimated the turbine power to be 3000W at 180rpm, in that case the torsional strain would be 54um/m, and therefore meet the criterion for torsional strain over a greater range.

Speed of the shaft was measured through an electronic revolution counter make Banner.

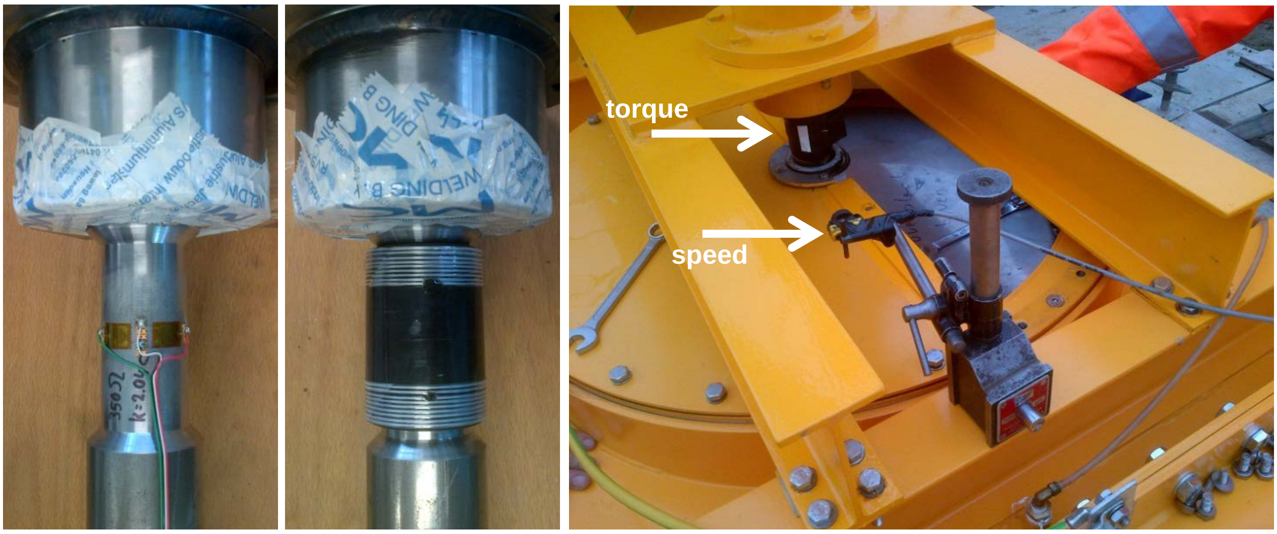

Figure 2: Strain gauges applied on Ø45mm shaft (left picture), encapsulated strain gauges (centre) and torque and speed measurement location in the test setup (right).

2.2 Flow

Flow in the pipeline (DN1000) feeding the test setup was measured using a clamp on transit time flowmeter, make GE Sensing, type PT878, with a measuring accuracy ± 2%. The flowmeter was applied on the inlet pipeline, the measurement location is shown in figure 3.

Figure 3: Measurement location transit time flowmeter, located on inlet pipeline.

2.3 Pressure

The pressure difference generated by the turbine was measured using two electronic pressure transducers (make GE Sensing, range -1 to 2 bar and make AE Sensors, range 0 to 1.5bar). Prior to the measurements the sensors were calibrated using a pressure calibrator make Tradinco, type TRAQC-7 PC. A calibration certificate of this device is shown in attachment B. The measuring inaccuracy with these sensors is ±0.5% of full scale, but the measured pressures are much lower than the applied sensor range. Therefore the measurement inaccuracy is estimated to be ±5% of the measured values.
Sensors with a more suitable range were not available on the requested short term and not deemed necessary based on the first estimation of the range. The measurement location is shown in figure 4.

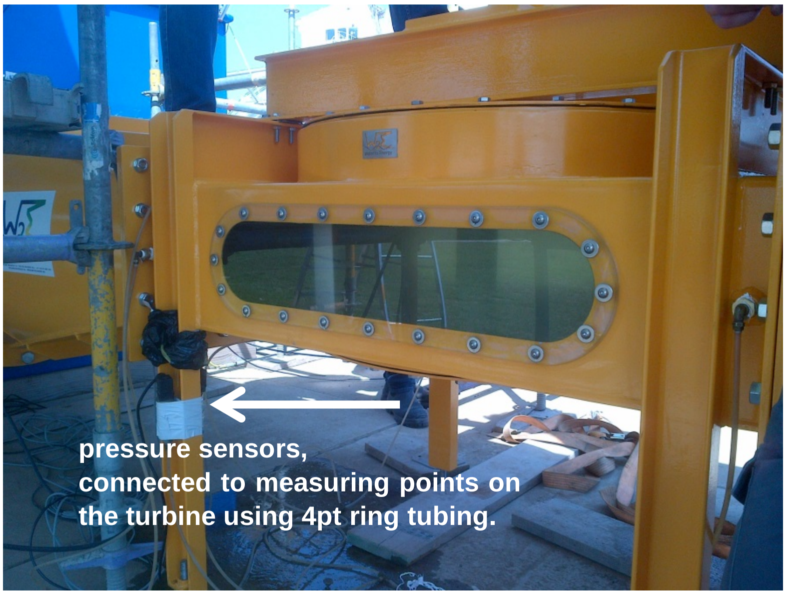

Figure 4: Measurement location pressure difference applied by the turbine.

3 Results

Time signals of the measurements are presented in attachments C. The measurements will be analysed in detail by Pro-Tide and the supplier of the turbine, W2E, for this purpose the raw data is provided. The different measurement conditions are tracked by Pro-Tide / W2E, and are displayed in the filenames of the data files.
However some characteristic plots are already made and presented in attachments D. The following signals and calculated results are plot in the attachments:

Measured:

Torque	[Nm]
Speed	[rpm]
Flow	[m/s] (flow velocity in DN1000 pipe)
Pressure1	[kPa]
Pressure2	[kPa]

Calculated:

VolumeFlow	[m3/s]	=	Flow * π * pipe_internal_diameter / 4 = Flow * 0.785
PressureDifference	[kPa]	=	Pressure1 – Pressure2
PowerMechanical	[W]	=	Torque * Speed * 2π / 60
PowerHydraulic	[W]	=	VolumeFlow * PressureDifference * 1000 (conversion from kPa to Pa)

The above signals are smoothened with a running average (window of 2 seconds). Hereafter the efficiency is calculated:

Calculated:

EfficiencyAfterAveraging	[%]	=	(PowerMechanical / PowerHydraulic) * 100

Note that because of the limitations in measuring accuracy of torque and pressure, the absolute value of the resulting efficiency should be considered as indication only (inaccuracy is estimated to be ±10%). However the relative difference in efficiency between different conditions can be considered to be more accurate.

4 Attachments list

A. Calculation of the torque scale factor

B. Calibration certificate Tradinco TRAQC-7 PC

C. Measurement results: time signals

D. Measurement results: characteristic plots

CALCULATION SCALE FACTOR TORQUE MEASUREMENT

MTI Measuring & Diagnostics

Ship: W2E turbine
Shaft: turbine shaft

Input

Shaft data

Power	P	1.62	[kW]
Speed	n	148	[rpm]
Diameter outward	D_o	0.045	[m]
Diameter inward	D_i	0.000	[m]
Shear module*	G	8.1939	[10^{10} N/m^2]

Strain gage data

Resistance	R_{stg}	0.35	[kΩ]
K-factor	k	2.04	[-]

* [for pump measurement, default G = 8.1939 * [10^{10} N/m^2], actual shear module is included in pump measurement sheet]

Calculation settings

Starting torque	$f_{M,start}$	1	* M_{nom}

Measurement system settings

Resistance calibration R**	R_c	437.4	[kΩ]
Scaleparts calibration	SP_c	7980	[SP]

** [Binsfeld: ref1 = 437.4 kΩ]

Calculation

Shaft torque / strain

Speed	ω	15.499	[rad/s]
Maximum torque	M_{max}	0.1045	[kNm]
Polair moment of inertia	I_p	0.00000	[m^3]
Maximum strain	ε_{max}	35.64812	[μm/m]

Strain gage calibration

Sensitivity at cal.	V_c	199.8858	[μV/V]
Simulated strain at cal.	ε_c	98.0616	[μm/m]
Simulated torque at cal.	M_c	0.2875	[kNm]
Scale factor	f	3.6E-05	[kNm/SP]
		0.036032	[Nm/SP]
	10V=	360.3166	[Nm]

Tradinco Instruments

The Calibration Company

T.C.L. Tradinco Calibration Laboratory

CALIBRATION CERTIFICATE

CALIBRATION RvA K 050

Certificate number : 21500587B

Applicant	MTI Holland B.V. Smitweg 6 2961 AW Kinderdijk
Instrument	Digital pressure calibrator
Manufacturer	Tradinco Instruments
Type	TRAQC-7 PC
Serial number	14.06.117/11653
Service number	17468
Customer identification number	-
Calibration method	This calibration is carried out with : Deadweight tester type : T2300/1 S/N : 6612/91 Cal. Due : 18 July 2018 During calibration a testpressure is put under a calibrated measuring piston which is loaded with calibrated weights
Environmental conditions	Temperature: 20.0°C ± 2°C Humidity: 55 %rh ± 25 %rh
Date / period of calibration	20 April 2015
Results	See following page(s)
Uncertainty	± 0.012 % of full scale with use of correction figures in the range of (0 ÷ 10) bar The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor of $k = 2$, which provides a confidence level of approximately 95 %. The standard uncertainty has been determined in accordance with document EA-4/02. Calculated by software revision: 2.7.6.6/2.33
Traceability	The measurements have been executed using standards for which the traceability to (inter)national standards has been demonstrated towards the RvA.
Date	20 April 2015
Name	S. Baidjnath-Misier Head of TCL

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2651 BD Berkel en Rodenrijs
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Tradinco Instruments®

The Calibration Company

T.C.L. Tradinco Calibration Laboratory

CALIBRATION CERTIFICATE

Certificate number : 21500587B

	Standard	Instrument
Service number		17468
Type	T2300/1	TRAQC-7 PC
Manufacturer	Tradinco Instruments	Tradinco Instruments
Description	Deadweight tester	Digital pressure calibrator
Serial number	6612/91	14.06.117/11653
Range	(0.2 ÷ 35) bar	(-1 ÷ 10) bar
Medium	Air	Air
Accuracy	±0.01 % R	±0.02 % FS full scale = 10 bar
Temperature	20.0°C ± 0.5°C	

	STANDARD		INSTRUMENT					
MP.	INPUT UP bar	INPUT DOWN bar	READING UP bar	READING DOWN bar	ERROR UP % FS	ERROR DOWN % FS	LIMIT UP % FS	LIMIT DOWN % FS
1	0.000000	0.000000	0.0000	0.0003	0.000	0.003	± 0.020	± 0.020
2	1.00001	1.00001	0.9998	0.9994	-0.002	-0.006	± 0.020	± 0.020
3	2.00006	2.00006	1.9998	1.9994	-0.003	-0.007	± 0.020	± 0.020
4	3.00015	3.00015	2.9998	2.9995	-0.004	-0.007	± 0.020	± 0.020
5	4.00022	4.00022	4.0001	3.9995	-0.001	-0.007	± 0.020	± 0.020
6	5.00026	5.00026	5.0001	4.9996	-0.002	-0.007	± 0.020	± 0.020
7	6.00040	6.00040	6.0002	5.9999	-0.002	-0.005	± 0.020	± 0.020
8	7.00045	7.00045	7.0005	7.0001	0.000	-0.004	± 0.020	± 0.020
9	8.00059	8.00059	8.0006	8.0003	0.000	-0.003	± 0.020	± 0.020
10	9.00066	9.00066	9.0012	9.0010	0.005	0.003	± 0.020	± 0.020
11	10.0007		10.0013		0.006		± 0.020	

This range has not been adjusted (As found is as left calibration).

Customer ID. no. : -

Customer ref. : 602510

Our ref. : 61500826

Customer : MTI Holland B.V.

Calibrated by

TCL Technician

P. Verhoef

Cal. date : 20 April 2015

Approved by

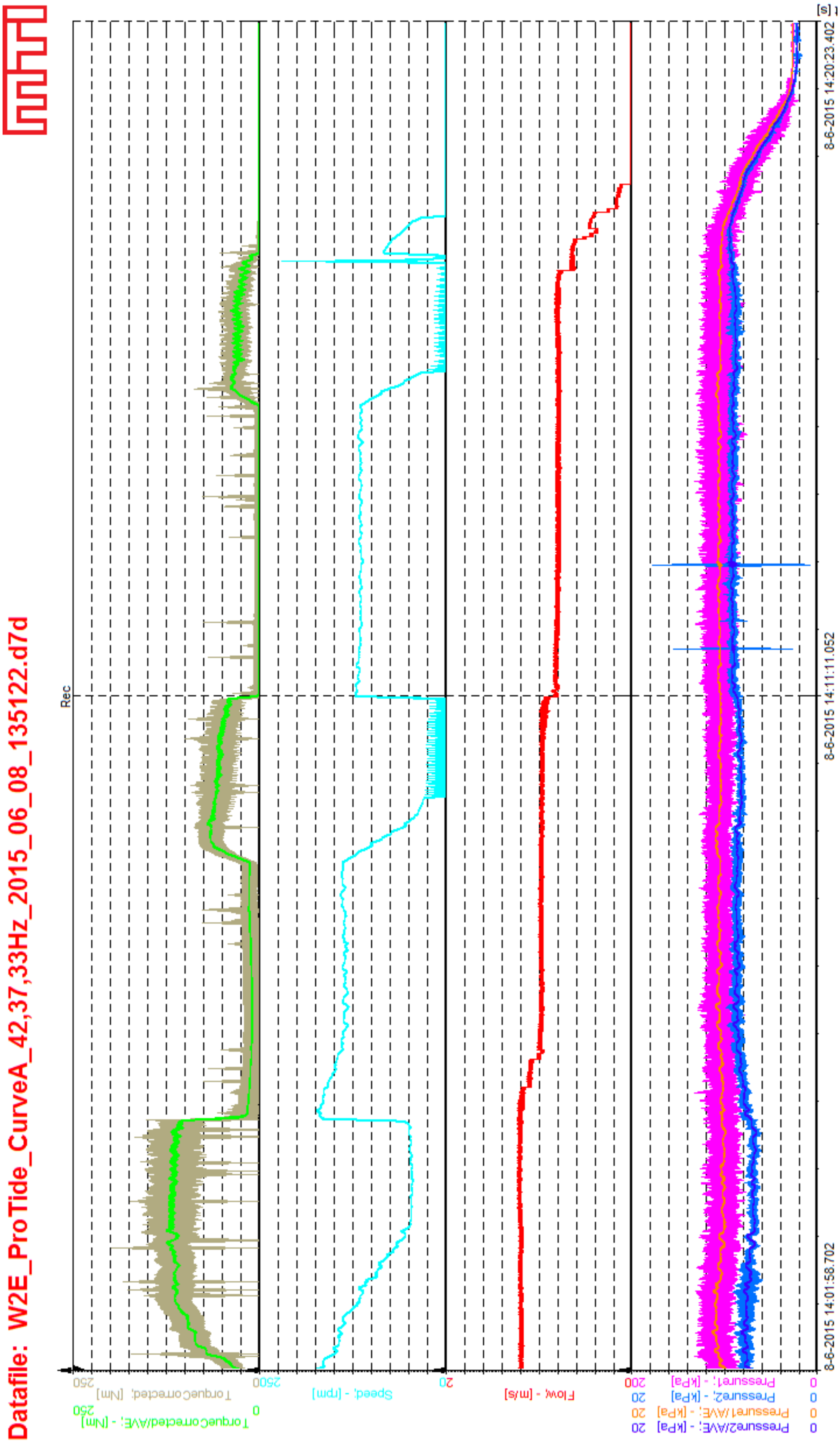
Head of TCL

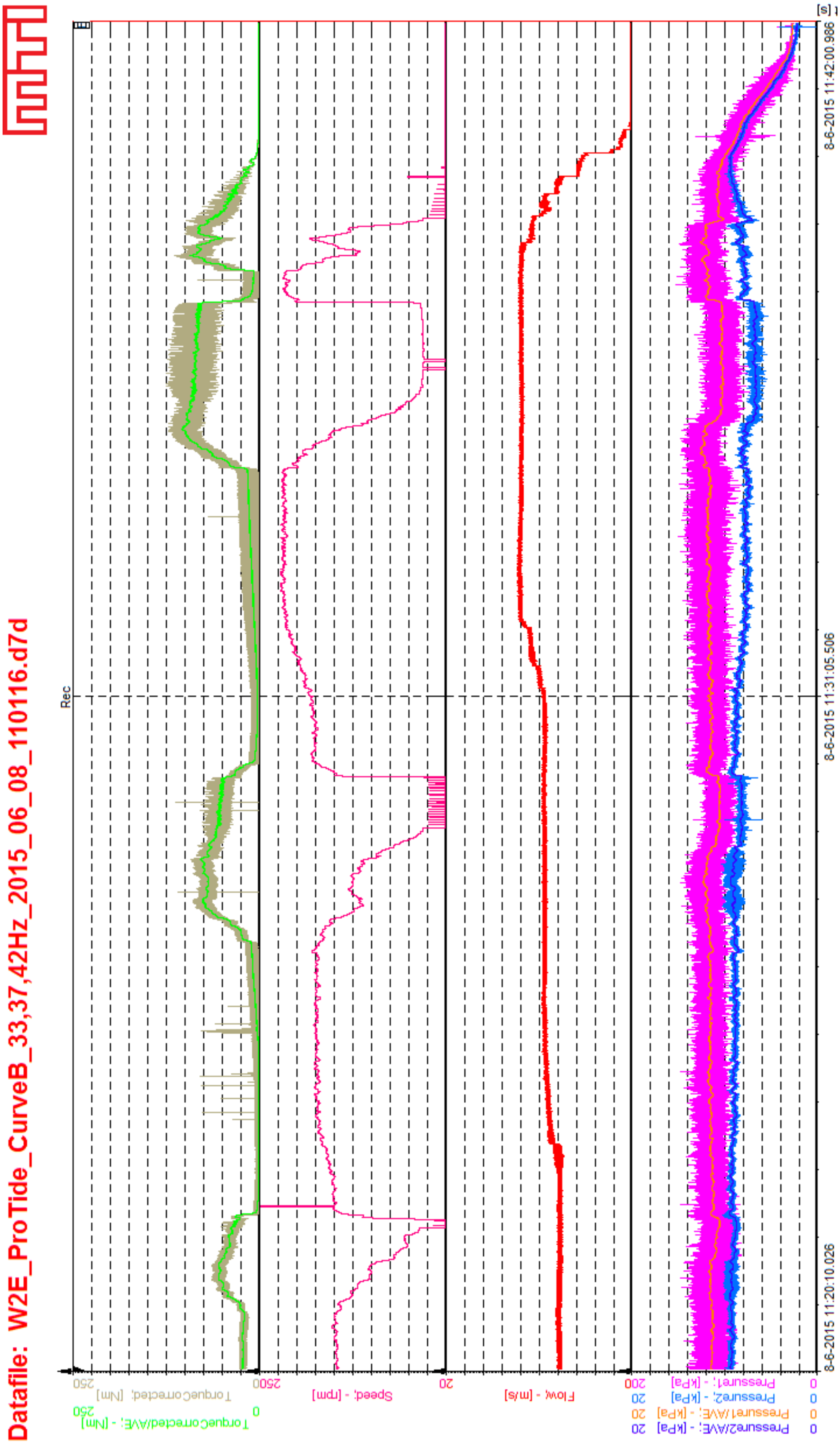
S. Baidjnath-Misier

Date : 20 April 2015

Berkel en Rodenrijs

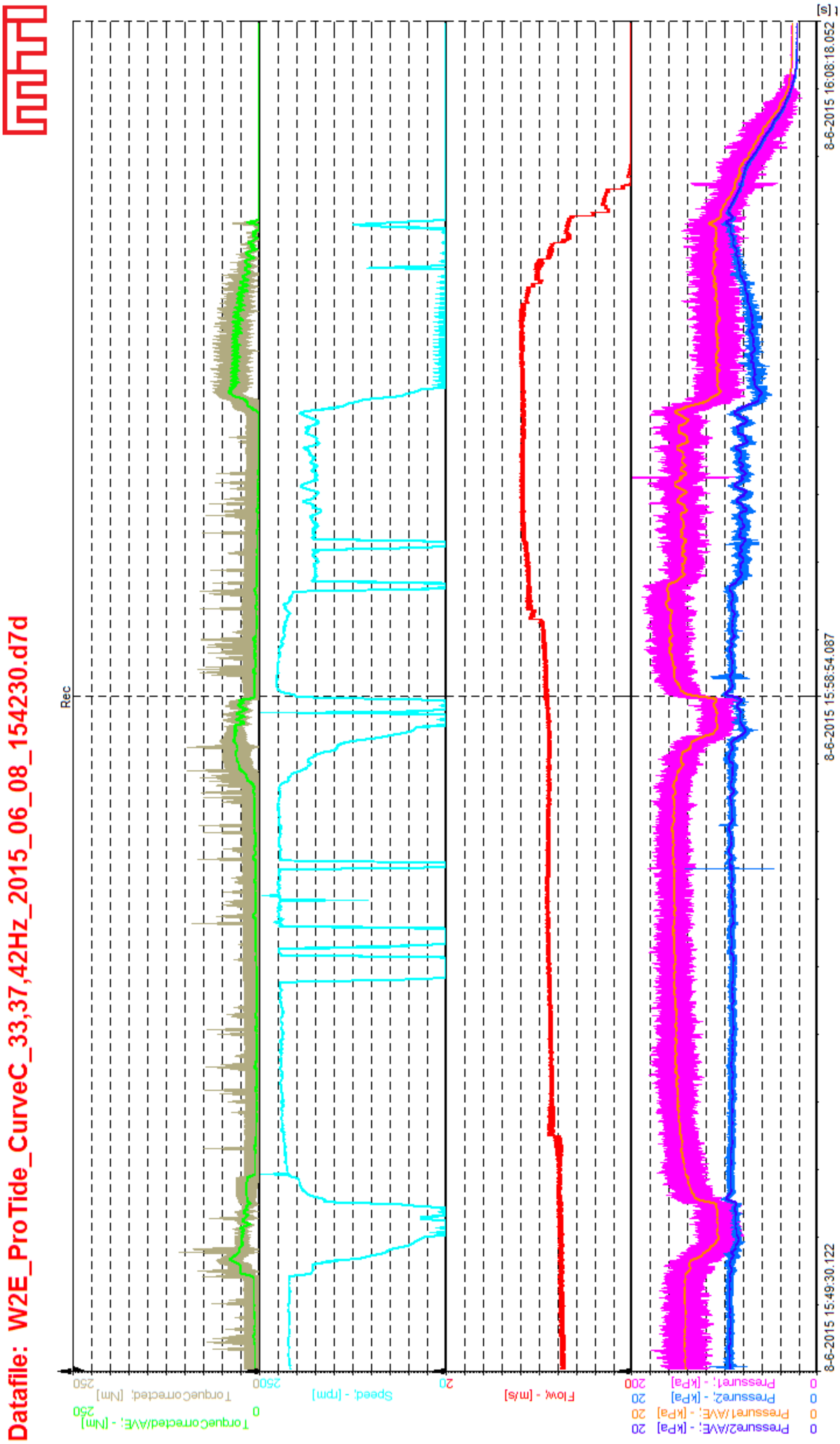
Appendix C : Measurement results: time signals



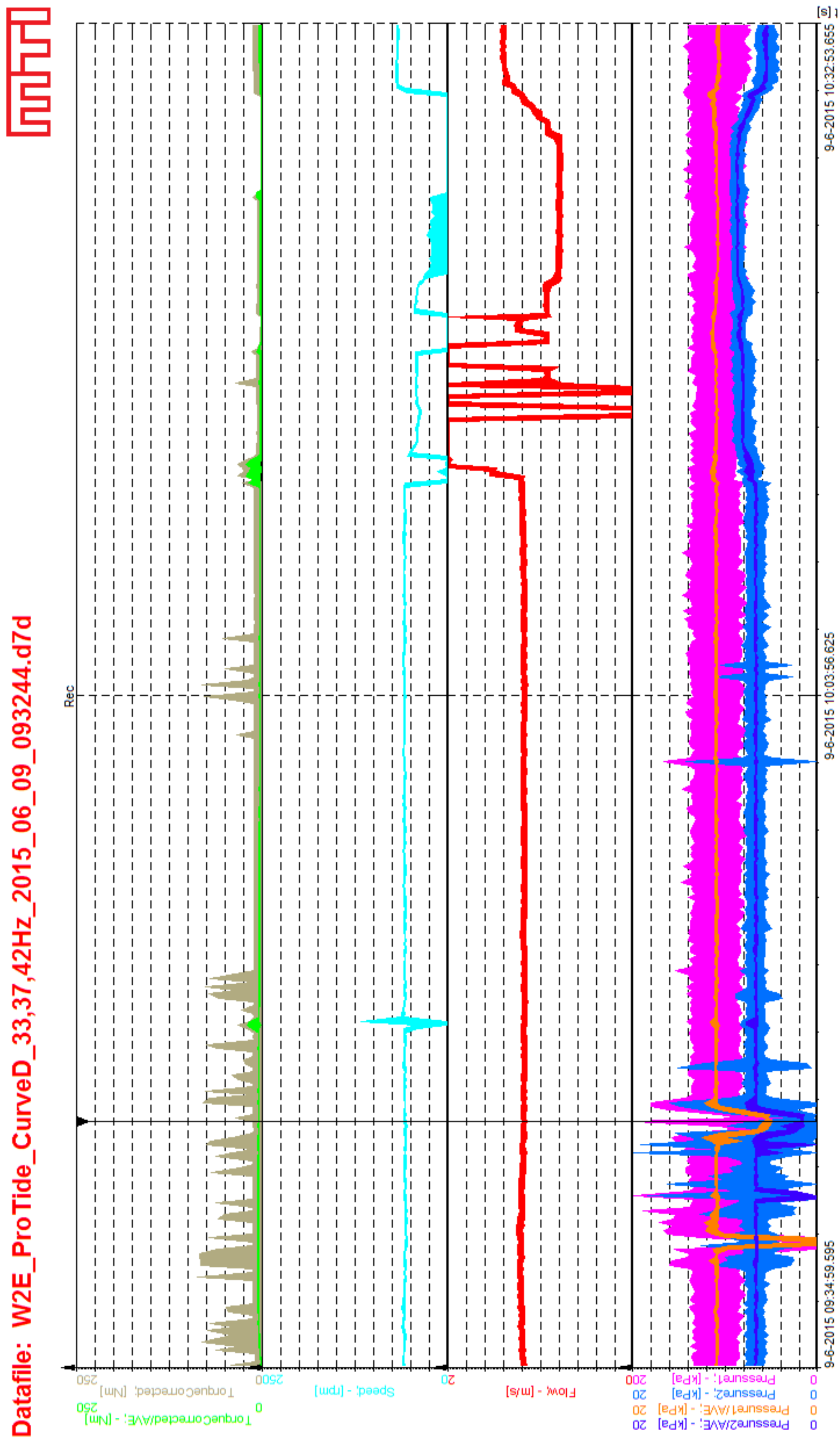


Datafile: W2E_ProTide_CurveB_33,37,42Hz_2015_06_08_110116.d7d
Rec
8-6-2015 11:42:00.986
8-6-2015 11:31:05.506
8-6-2015 11:20:10.026
[s]
TorqueCorrected; [Nm]
TorqueCorrected/AVE; - [Nm]
Speed; - [rpm]
Flow; - [m/s]
Pressure1; - [kPa]
Pressure2; - [kPa]
Pressure1/AVE; - [kPa]
Pressure2/AVE; - [kPa]

Date	Reference	Version	Status	Attachments
10-8-2015	DIV240	V1.1	Final	



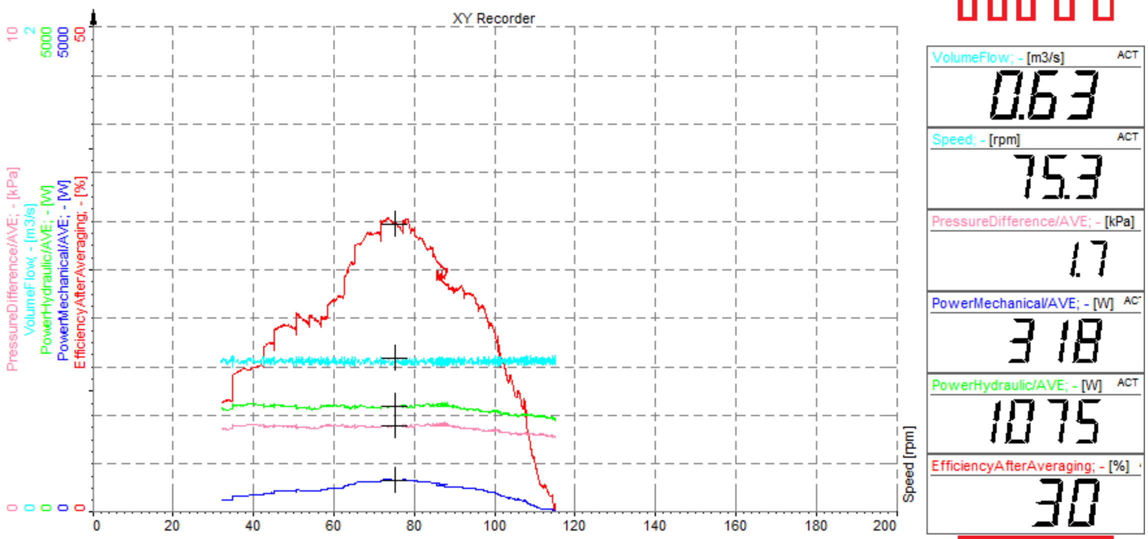
Date	Reference	Version	Status	Attachments
10-8-2015	DIV240	V1.1	Final	



Date 10-8-2015 | Reference DIV240 | Version V1.1 | Status Final | Attachments

Appendix D : Measurement results: characteristic plots

Datafile: W2E_ProTide_CurveA_42,37,33Hz_2015_06_08_135122.d7d



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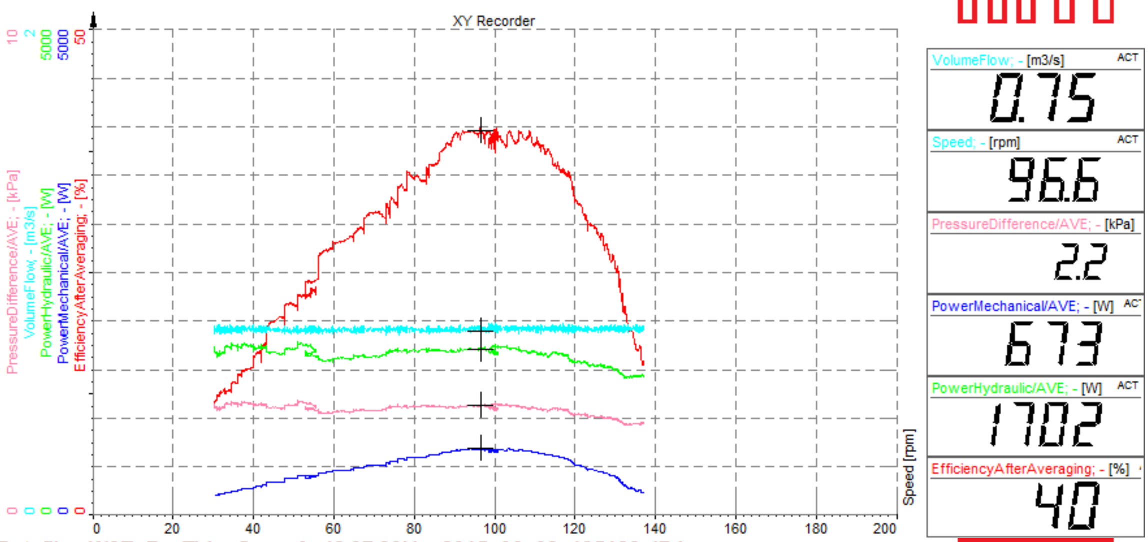

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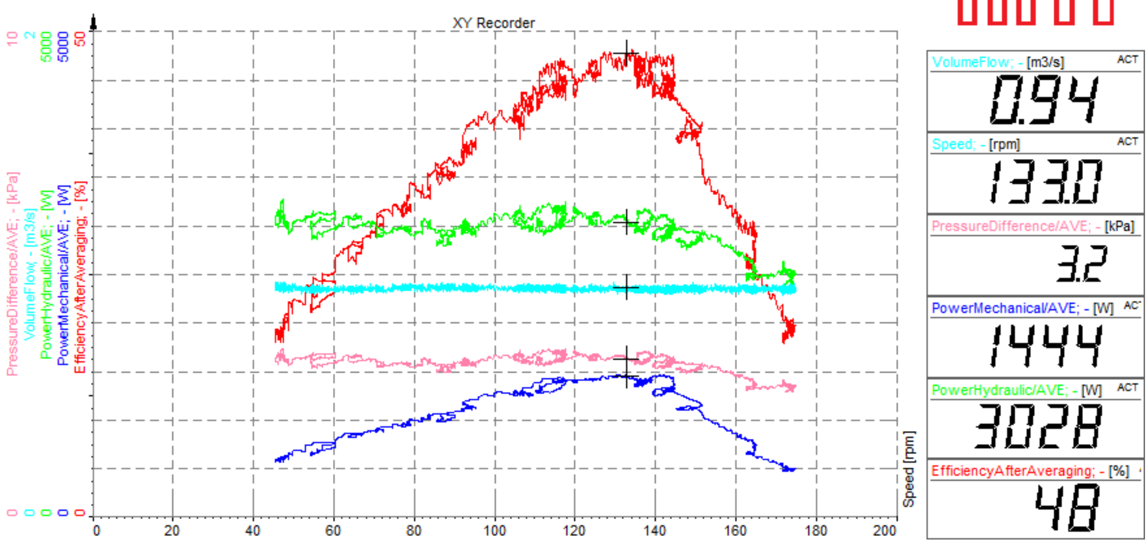

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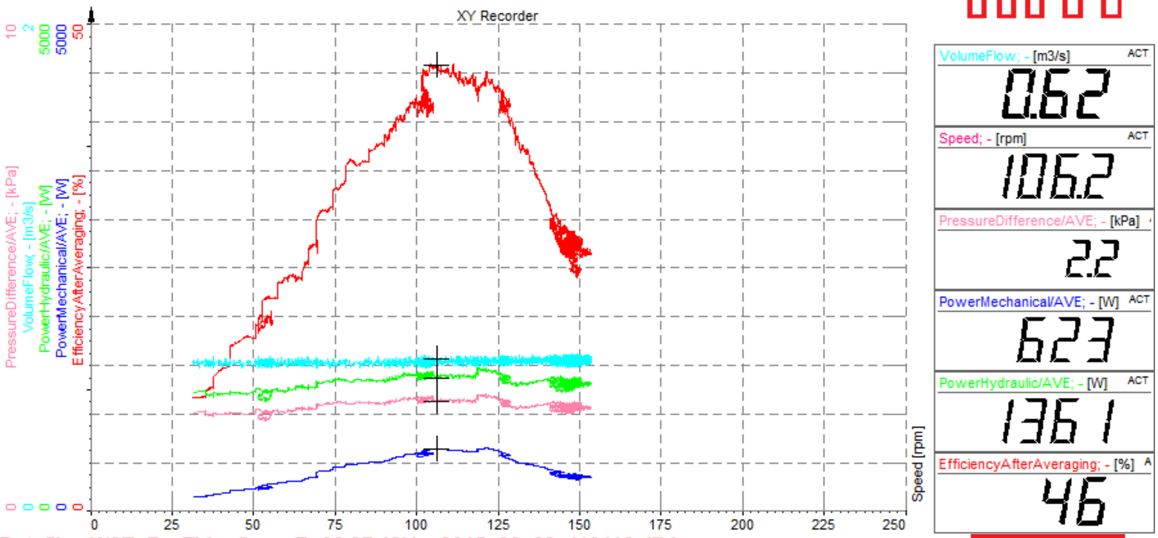

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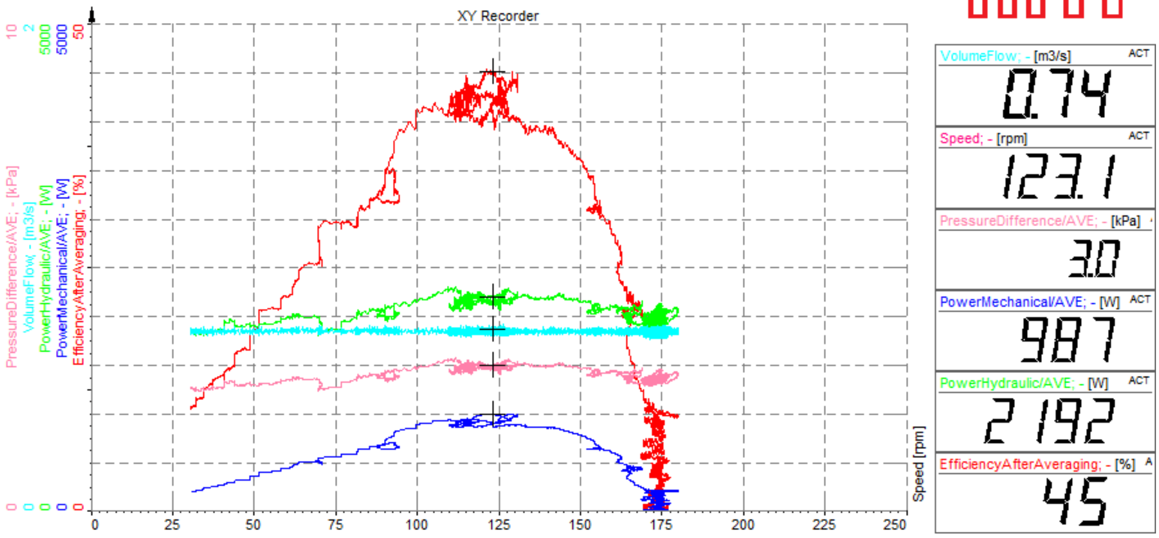

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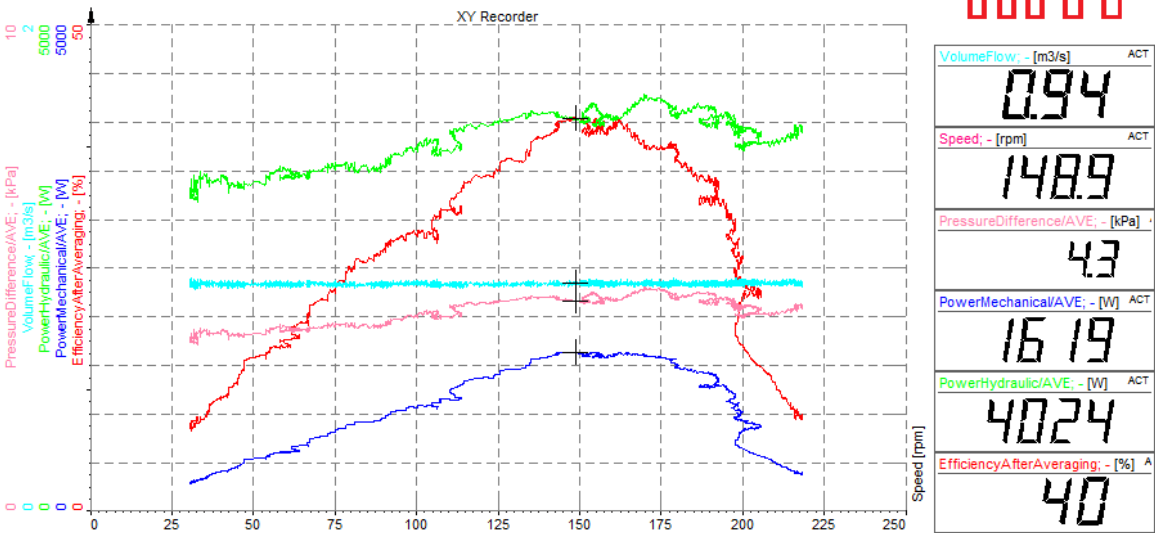

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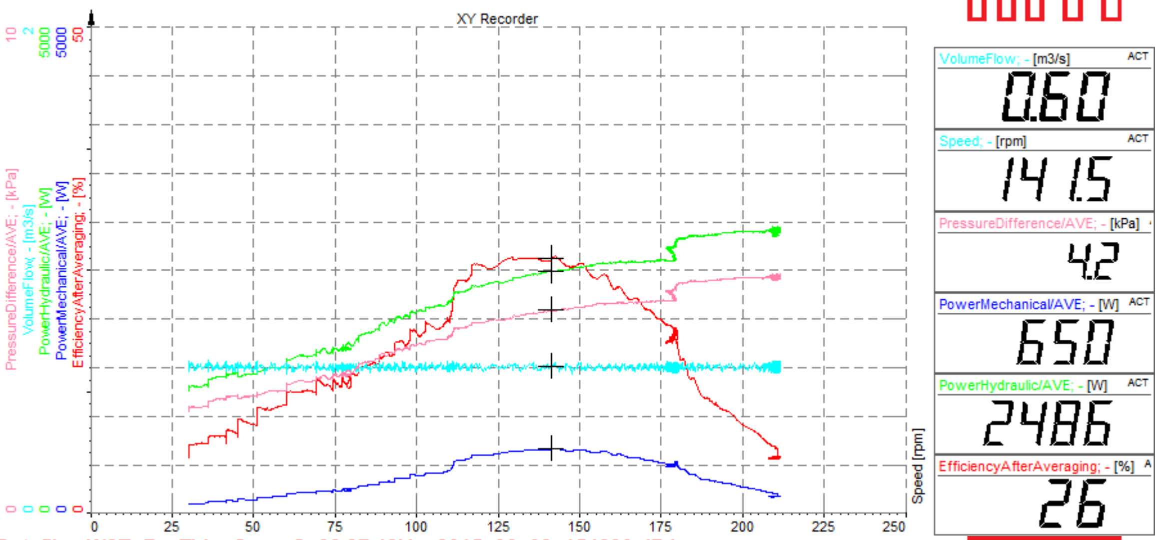

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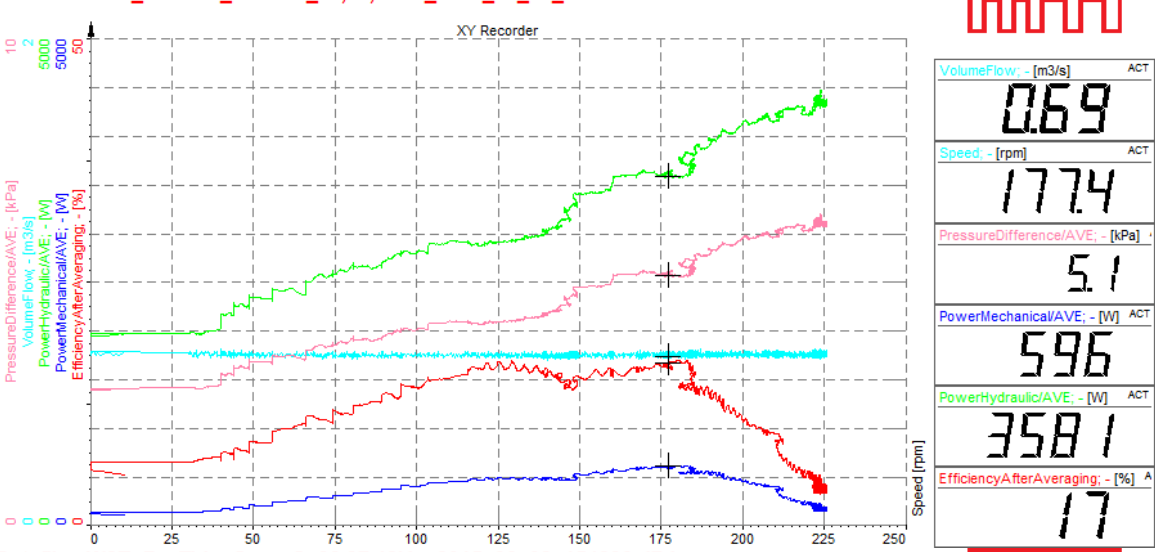

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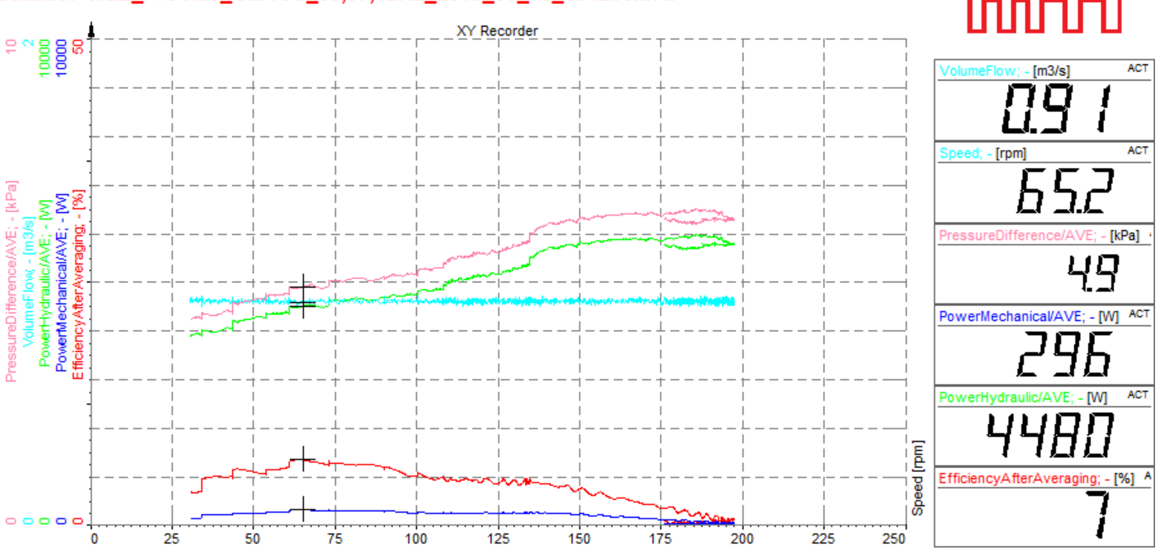

N.B.: Note different Power scaling in vertical axis in last graph.