Condition Monitoring of Hydraulic Systems

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Sammanfattning

Syftet för detta projekt är att utreda och föreslå ett system för tillståndsövervakning och analys av en skogsmaskins hydraulsystem baserat på tillgängliga data från ombordmonterade partikelsensorer. Den maskin som studerats är Ponsse Scorpion King, som är utrustad med partikelsensorn Icount PDR från Parker. Data samlades in under en två veckor lång fälttest. Maskinoperationerna och mätdata från partikelräknaren samlades in, och orsakerna till avbrott längre än fem minuter loggades manuellt. Resultatet av detta examensarbete presenterar relationerna mellan tre faktorer: partikelantal hos hydrauloljan, maskinens verksamhet och de avbrott som inträffade. Denna avhandling avser också föreslå hur informationen från Icount PDR skall presenteras för operatören och hur förebyggande maskinunderhåll skall kunna planeras.

Nyckelord: *Partikelräknare, maskindrift, driftsavbrott*

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Approved	Examiner	Supervisor
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Abstract

The purpose of this project is to investigate and propose a system for condition monitoring and analysis of the hydraulic system of a forestry machine based on available on-board oil quality sensor data. The sample machine used was Scorpion King from Ponsse. This machine is equipped with an Icount PDR particle sensor from Parker. A two weeks long field test was conducted by Skogforsk. The data measured by the particle counter was collected, and breaks longer than five minutes were recorded as well as the reason for each break. The main results from the thesis are the relations between three factors: number of particles in the oil, machine operations, and machine breaks. The thesis also aims at proposing how the operator could use the Icount PDR data to manage the maintenance of the machine.

Keywords: *Particle counter, machine operations, machine breaks*

FOREWORD

I would thank people from Skogforsk and Ulf Sellgen for this thesis proposal and the trust you giveme. My indeed appreciation goes to Björn Löfgren and Ulf Sellgen, owing to their supervising through the entire project.

Then I would thank Virkkunen Eveliina from Ponsse who has provided me with a lot of documents that have helped me to understand the project, the hydraulic system of the machine, and also the usege of the particle counter. Many thanks to Jani Savuoja from Creanex, who has helped me a lot to use the machine operation data. Also thank to Arlinger John who applied the utility program to read the ".drt" files for the record of machine breaks.

Additional thanks go to Johan Forsberg who wrote the master´s thesis "Model Based Study of the energy efficiency of two different types of harvester cranes". This thesis helped me a lot to understand the hydraulic system of harvester cranes. And I want to thank all the people that have shared me with their opinions on this project.

Finally I want to give my deepest gratitude to my family for financially supporting my master study. This journey will be memorable during my entire life.

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NOMENCLATURE

Abbreviations

OpMon	Operational Monitoring of Forest Machine
Matlab	Matrix Laboratory

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1 INTRODUCTION

1.1 Background

The predominant forest harvesting method is the cut-to-length method, based on a two-machine solution - a harvester that folds, branches and cut trees, and a forwarder transporting logs to a landing area for further transport to a processing facility (KTH and Skogforsk, 2015).

Both the harvester and the forwarder rely on a robust and reliable hydraulic boom crane and reliable hydraulics to operate the tools such as harvester head and grapple needed to successfully and rapidly harvest and forward logs. As a measure to improve the energy efficiency of the forest machines, optimization is desired. For the harvester and forwarder booms, one way to improve them is to look at the efficiency of the hydraulics, namely the hydraulic for the boom./2/

The harvesting productivity depend significantly on the machine availability, i.e. on mean-time-between failures (MTBF) and meantime-to-repair (MTTR). Hydraulic system failures usually have to be repaired in the field (KTH and Skogforsk, 2015).

There is a strong need to identify the need for maintenance before an actual failure occurs, e.g. to have a system for condition monitoring that is capable of identifying the condition of system critical components (KTH and Skogforsk, 2015).

Condition monitoring is the process of monitoring a parameter of condition in machinery (Wikipedia). It is usually used in systems to identify the upcoming fault or the requirement of machine maintenance. So the machine could be fixed before the real failure which will cost a huge amount of money. The key to a successful condition monitoring program includes following factors. Successfully using this program enables the repair of problem components prior to failure.

- Knowing what to listen for
- How to interpret it
- When to put this knowledge to use

1.2 Purpose

The purpose of the project will therefore be, in the first place, to investigate and propose condition monitoring of the vehicle hydraulic system. Additionally, the measuring data from on-board sensors should be analyzed. The best usage of the collected data would be to be able to use it in precautionary maintenance. So that the data reveals the need for service, or lets the driver know that everything is all right.

Analyzing the data includes following tasks:

- How to collect the data (via cloud service, at the site where the machine is, etc.),

- How to process the data (filter the data, interpret different situations),

- How to inform the operator about the condition of the hydraulic oil (user interface, how much knowledge to the operator and how, etc).

1.3 Delimitations

In order to clarify the objectives of the project, the delimitations should be defined in the early stage.

Firstly, this project is based on Ponsses' machines so that all the parameters (on-board oil quality data) will based on data available from a Ponsse harvester. And in the real situation, the field test which will last for two weeks has been set for the Scorpion King harvester. So the measured data is limited to this specific machine. Furthermore, the recorded data is measured with the sensor icountPDR, which might has its own working pattern. This sensor might also have some measuring limitations. This task is based on hydraulic system but the vehicles might also have an electrical system which might influence the measuring result.

Then to consider about the driving pattern, the different way of controlling the machine will not be treated in this project.

1.4 Method

In order to start the project, an investigation of the existing measuring system should be done. To begin with, the information on the sensor icountPDR, was offered including the user manual and measuring samples. Basically, these documents must be read and understood. After that, the measured data should be analyzed, to try to find out how the operator could use the data to predict the required maintenance of the machine.

At the same time, the number of particles may also connect to the operations of the machine. So the machine operations should also be recorded. The variation of the number of particles for each operation should be analyzed, in order to find out how different operations cause changes in the number of recorded particles.

Besides, the machine may stop for some reasons. Usually it should be at a normal state when it starts again, but if the particle counter gives a "strange" value, it might indicate some broken component.

2 FRAME OF REFERENCE AND METHODOLOGY

2.1 Scorpion King

Scorpion King is an eight-wheeled forest machine made by Ponsse, as shown in Figure 1. It is used for logging. The hydraulic system of this machine could be divided into five subsystems. The most important subsystem is the crane system, which is the one that should be monitored in this project. The crane movements could be divided into two parts, crane movements and harvester (head) movements.

Coming into details, as shown in Appendix A, the condition monitoring system should be used to monitor the primary movements of both crane and harvester. The crane movements include extension, luffing, and lifting. And the actions of the harvester are tilting, rotating, feeding, and knife-cutting.

Figure 1 Scorpion King

2.2 Failure mode of hydraulic systems

System failures are costly, followed by expensive maintenance, loss of production, environmental damages, and finally loss of image in the fluid power industry. The causes of system failures are abundant in nature. Defective maintenance and care of hydraulic systems are herewith still the simplest to recognize. (George et al., 2001)

Since the hydraulic system consists of different types of hydraulic components, including pumps, motors, different valves, cylinders. etc., the failure modes for different components will also be different. Following is a brief list of some typical failure modes of some commonly used components of the system:

- Valve

✓ Fails to shift
✓ Not function to standard
✓ Valve spool response sluggish
✓ Valve produces undesired response

- Actuators

✓ Cylinder rod seal leaking oil
✓ Erratic action

- Pump

✓ Excessive pump noise
✓ System excessively hot
✓ Leakage at oil seal
✓ Pump not delivering oil
✓ Pump not delivering pressure

- Motors

✓ Motor turning in wrong direction
✓ External oil leakage from motor
✓ Motor not turning over or not developing proper speed or torque (Advanced Fluid Systems)

From the list, most of the failure modes are related to the use of the oil, and as a result, in order to avoid some of the machine failures and to extend the service life of the machine, it is extremely important to choose, monitor, and change the oil during the life of the machine.

2.3 Condition Monitoring

Condition monitoring (CM) is the process of monitoring a parameter of the condition in a machine (vibration, temperature etc.), in order to identify a significant change which is indicative of a developing fault. It is a major component of CM to predict the need of maintenance. The use of condition monitoring allows maintenance to be scheduled, or other actions to be taken to prevent failure and avoid its consequences (Wikipedia, 2015)

Condition monitoring has a unique benefit in that conditions that would shorten normal lifespan can be addressed before they develop into a major failure. Condition monitoring techniques are normally used on rotating equipment and other, while periodic inspection using non-destructive testing techniques and fit for service (FFS) evaluation are used for stationary plant equipment such as steam boilers, piping and heat exchangers (Wikipedia, 2015).

On vehicles, there are usually many types of sensors used for monitoring the whole system from different functions including pressure sensor, load sensor, acceleration sensor, vibration sensor, temperature sensor and particle counter. Shown below, is a typical condition monitoring system of heavy vehicles. The pressure sensor is used to monitor the driving and steering system, and in addition the acceleration sensor is also used to survey the status of the engine.

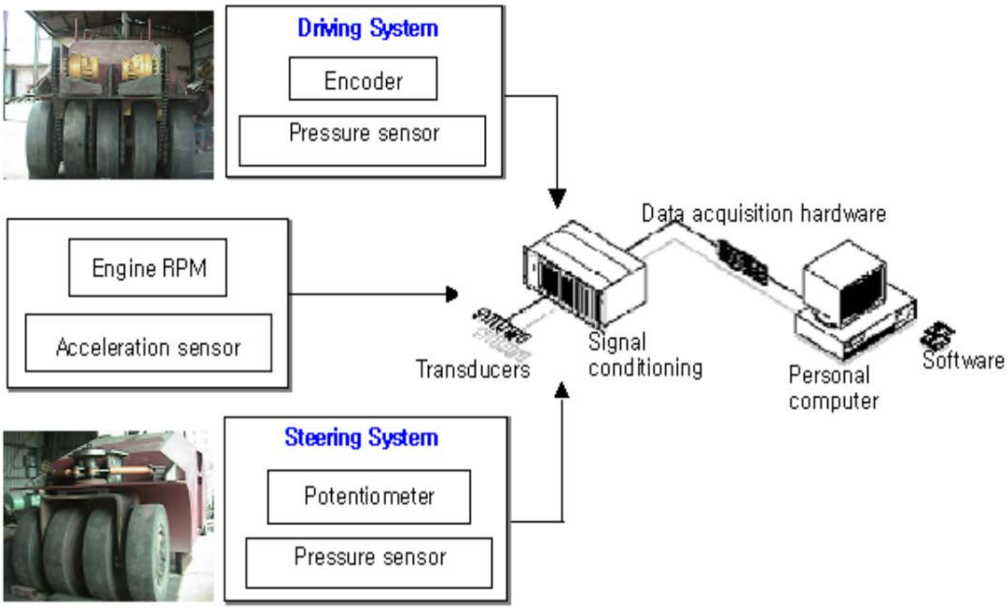


Figure 2 An example of a condition monitoring system

In Scorpion King, there are totally three sensors that have been used to monitor the system. One particle counter is mounted on the output line and two temperature sensors are separately mounted inside the tank and outside the machine.

2.4 The useful oil data

Because of the importance of the oil data, the properties of the oil before it is put into the system should be investigated. Usually, e.g. from Internet, it is easy to find basic information for different oils, including name, type, series number, where to use it, and also the viscosity at different temperatures.

After the oil has been chosen and put in use, it is necessary to do test it periodically. The test should indicate changes of the contaminants, which may influence the properties of the oil. This kind of test should helpful for the oil changes. The following figure is an example of results from a test of the oil used in Scorpion King.

The tests that were performed at Linköping University, investigated the oil used in the machine and then compared it with a reference oil, to see whether or not the oil could still be working perfectly. This was a chemical analysis that included the test results of different contaminants and the number of particles, and their size distribution. If the collected data from H1081 used in Scorpion King was similar to the data from reference oil then it should be considered as still working.

Analys av oljeprov från Scorpion A010049

Inledning:	Oljeprov märkt enligt nedan ankom till Exova AB	2015-01-15	
Resultat:	Flask nr:	Referensolja	H1081
	Maskintyp:	-	Scorpion
	Serie/Chassi nr:	-	A010049
	Drifttid:	-	419
	Oljetyp:	Panolin HLP Synthetic 46	Panolin HLP Synthetic 46
	Oljepåfyllning:	-	85
	Provdatum:	2015-01-14	2015-01-08
	Vårt provnr	517	518

Provad egenskap	Enhet			Metod	*Mätosäkerhet*
SOAP-analys	mg/kg			ASTM D 5185-09 mod*)	*±30% vid 10 ppm*
Nötningsmetaller					
Silver, Ag		<0,05	<0,05		
Aluminium, Al		<0,20	<0,20		
Kadmium, Cd		<0,05	<0,05		
Krom, Cr		0,08	0,47		
Koppar, Cu		<0,02	2,41		
Järn, Fe		<0,10	3,13		
Mangan, Mn		<0,01	0,08		
Molybden, Mo		<0,30	<0,30		
Nickel, Ni		<0,20	<0,20		
Bly, Pb		<0,70	<0,70		
Tenn, Sn		<0,60	<0,60		
Titan, Ti		0,14	0,29		
Vanadin, V		<0,05	<0,05		
Additiver					
Bor, B		0,55	0,93		
Barium, Ba		<0,01	0,04		
Kalcium, Ca		0,11	1,64		
Magnesium, Mg		<0,20	<0,20		
Fosfor, P		1460	1400		
Zink, Zn		<0,30	11,2		
Föroreningar					
Natrium, Na		<0,30	0,54		
Kisel, Si		0,60	1,41		
Vattenhalt - KF	mg/kg	230	190	ASTM D 6304-07 mod*)	*±25% (50-1000mg/kg)*
Andra analyser					
Utseende		ua	ua		
Viskositet vid 40 °C	mm²/s	46,14	46,65	ASTM D 445-11a*)	*±0.3%*
Syratal, TAN*	mg KOH/g	0,43	0,40	ASTM D 664-07 mod*)	*±26% vid 1.5*
Partikelräkning	antal/100 ml			ISO 5884 mod/ISO 11171*)	
> 4 µm (c)		122 000	11 900		*±15%*
> 6 µm (c)		14 200	1 480		*±20%*
> 14 µm (c)		510	50		*±30%*
> 21 µm (c)		250	20		
> 38 µm (c)		40	0		
> 70 µm (c)		10	0		
ISO kod		17/14/10	14/11/6	ISO 4406-99	

*) Ackrediterad metod

2015-01-21

Fuel & Lubricant Testing, Chemical Analysis, Linköping

Figure 3 Fuel and Lubricant Testing

2.5 Icount PDR

IcountPDR is the particle counter used in the Scorpion King. The IcountPDR is a compact, permanently-mounted laser-based particle detector module for fluid management and contamination control.

Every minute, the amount of particles per 100 mL of four different sizes: 4µm, 6µm, 14µm and 30µm per 100 milliliters, was measured by an IcountPDR mounted in the hydraulic transmission line of a Scorpion King. With the same frequency, the relative humidity of the oil sample was measured. The technical specifications could be seen in appendix D.

Figure 4 IcountPDR (Parker Hannifin, 2011)

2.6 Software Tiwalde

In order to monitor the hydraulic system, it is important to record all the situations in the machine, including the machine breaks and the machine operations. The software Tiwalde was developed by the company Creanex for Ponsse forest machine field measurement and analysis purposes. Tiwalde can read data from multiple sources, such as CAN buses and external A/D converters, but most importantly, it can operate directly under the Opti4G control system without any hardware installation. Measured data channels and the data output format are both highly configurable (Creanex Oy, 2015). The recorded data could be read directly by the software Matlab.

2.7 Software SilviA

The monitoring system should not only relate to the machine breaks, but also to the machine operations. The software SilviA can be used to record all the machine breaks which are lasting more than five minutes. Since Skoforsk could not give access to the software, they can extract the file and the application called OpMon, which is shorts for “Operational Monitoring of forest machine”, can be used to read the recorded breaks. The reasons for these stops could be divided into two groups: non-stop and stop reasons. The non-stop standstill include regular breaks and repairing breaks. The goal of this thesis is to find how these breaks influenced the particle metering.

2.8 Matlab

In this project, Matlab played an important role during the whole analyzis process. At first, it was used to read the recorded data which was collected with Tiwalde. The company who developed the software Tiwalde also made a Matlab code. When extracting the measured data, it is necessary to run the code firstly, and then use the command shown as follows, to see the data.

Command: load_signal_logger_data(‘filename’)

The Matlab code could be seen in Appendix B.

Then for the measured data from the particle counter, it is necessary to use Matlab to plot the data which is helpful for the analysis work. Since the “.txt” file could not be imported directly into Matlab, Excel was used as an inter-medium to extract the data in the “.txt” file and deliver the data to Matlab. In order to read the Excel file, a simple Matlab code was built. Since the field test didlast for two weeks, there is a need to be careful when extracting the day-by-day data. So the Matlab code which has shown in Appendix B is pretty simple and just repeated for many times.

3 THE PROCESS

3.1 Project directives

The aim of this project is to use a particle counter to monitor the hydraulic system of a forest machine called Scopion King. The particle counter icountPDR will measure the amount of particles in the hydraulic oil that passes the sensor each minute. The machine operations and the machine breaks were recorded. The directives of this project could be summarized as follows:

- Analyze the measured data from the particle counter to find out the informal values which indicate the requirement of repairing machine.
- Combine the counted particle values with the machine operations, to find the relations between them, to know whether or not the machine operations will influence the number of measured particles.
- Find out the relations between machine breaks and the number of particles measured.

3.2 Analysis of the Operations of Scorpion King

First of all, the machine operations have been analyzed. Since the machine operations is divided into 67 channels, it is necessary to minimize the number of items that are related to the hydraulic system. All the operations have been listed in table 1.

Totally, the operations could be divided into groups: Command, Sensor and Counter, Movement. Basically, the command operations are more like to apply a word or to press a button to tell the machine which operation should be made at the next step. From table 1, it is easily to find the operations which are giving a command to the machine. Besides, comparing the operations for joystick and valve, we could say, that the joystick operations are applying a command to the valve to move. So the joystick operations could also be classified into the “Command” group, which are not related to the hydraulic system. Totally, the items concluded in this group are:.

Command: 14, 20~34, 52~64

Sensor and counter are electrical devices that, for example, are used to count the number of trees which is not related to the hydraulic system. The items for these kinds of operations could be ignored in the present work. The machine movements relate to valve, cylinder, fuel and engine. These items, consequently, should be analyzed.

Based on these groups, all 67 operations could be classified as follows:

Sensor and Counter: 1, 15, 44, 45, 47~50, 65~67

Movement: 7, 9~11, 18, 19, 32~43

Table 1 The recorded operations of Scorpion King (Creanex Oy, 2015)

Column	**Data Type**	**Column**	**Data Type**
1	Time elapsed from the measurement start (in seconds)	35	Valve, lift up
2	Drive gear	36	Valve, transfer out
3	Working brake state	37	Valve, transfer in
4	Drive direction switch, forward position active	38	Valve, extend in
5	Drive direction switch, backward position active	39	Valve, extend out
6	Transmission active direction	40	Valve, rotator left
7	Drive Speed	41	Valve, rotator right
8	Drive distance	42	Valve, grapple close (only forwarder reports this data)
9	Fuel consumption, momentary	43	Valve, grapple open (only forwarder reports this data)
10	Diesel rpm	44	Stem length measurement
11	Diesel load percentage	45	Stem diameter measurement
12	Gas pedal, front	46	Feeding speed
13	Gas pedal, back	47	Current tree species
14	Transmission RPM command	48	Previous tree species
15	Transmission RPM sensor	49	Previous assortment
16	Frame steering joystick, left	50	Saw cut progress percentage
17	Frame steering joystick, right	51	Saw cut type (felling/ cutting)
18	Frame steering valve, left	52	Manual feeding command, forward
19	Frame steering valve, right	53	Manual feeding command, backward
20	Joystick, swing left	54	Feed propo command, forward
21	Joystick, swing right	55	Feed propo command, backward
22	Joystick, lift down	56	Rear knives open command
23	Joystick, lift up	57	Rear knives close command
24	Joystick, transfer out	58	Rear knives propo command
25	Joystick, transfer in	59	Front knives open command
26	Joystick, extend in	60	Front knives close command
27	Joystick, extend out	61	Front knives propo command
28	Joystick, rotator left	62	Feed rolls open command
29	Joystick, rotator right	63	Feed rolls close command
30	Joystick, grapple close (only forwarder reports this data)	64	Feed rolls propo command
31	Joystick, grapple open (only forwarder reports this data)	65	Tilt sensor
32	Valve, swing left	66	Event counter, felling
33	Valve, swing right	67	Event counter, tilt up
34	Valve, lift down		

In order to double check the variation of each item, a linear graph for each item was plotted. It is easy to see that there are totally three different kind of situations. The following figure shows a type, which has not changed during the whole day. This means that such an operation has not been manipulated in that day.

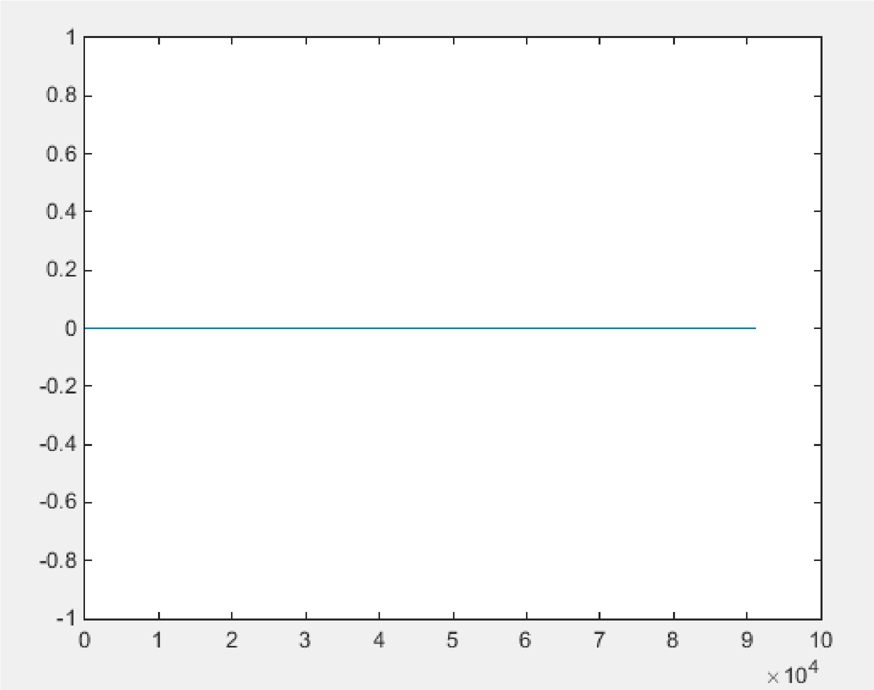
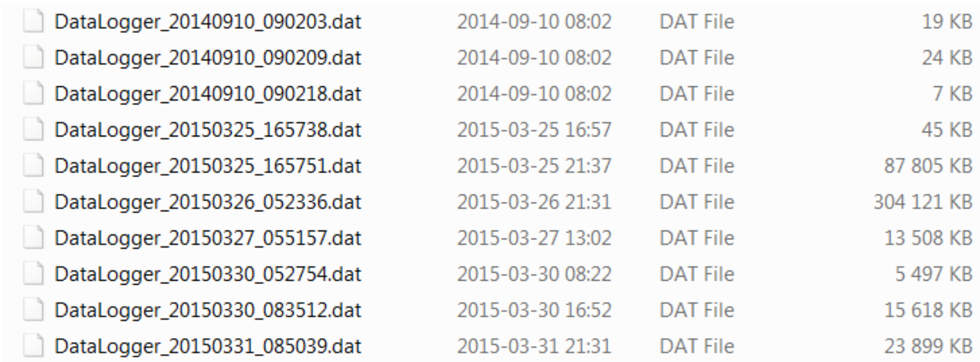


Figure 5 An instance for operation which measurement has not been changed during the whole day

Totally, there are 26 items that have not changed during the work time, which implies that they could be ignored. These items are: 2, 8, 13, 14, 16, 17, 30, 31, 40 ~ 43, 54~ 67. A look at the items which have been kept, shows that some of them can be paired, like “valve extend in” and “valve extend out”, and they should have the opposite measured value because the valve could not extend in and out at the same time. So we only need to consider one item in a pair. With these considerations, the operations which should be analyzed can be substantially decreased. The operations which are assumed to have an influence on changing the amount of particles in the fluid are:

Operations 18, 19, 32~39

The file was saved as a “.dat” file, and their names were made by the beginning time of the measurement as shown in the figure. For example, the first file name in figure 6 indicates that the measurement started at 09:02:03 on 10/09/2014.



DataLogger_20140910_090203.dat	2014-09-10 08:02	DAT File	19 KB
DataLogger_20140910_090209.dat	2014-09-10 08:02	DAT File	24 KB
DataLogger_20140910_090218.dat	2014-09-10 08:02	DAT File	7 KB
DataLogger_20150325_165738.dat	2015-03-25 16:57	DAT File	45 KB
DataLogger_20150325_165751.dat	2015-03-25 21:37	DAT File	87 805 KB
DataLogger_20150326_052336.dat	2015-03-26 21:31	DAT File	304 121 KB
DataLogger_20150327_055157.dat	2015-03-27 13:02	DAT File	13 508 KB
DataLogger_20150330_052754.dat	2015-03-30 08:22	DAT File	5 497 KB
DataLogger_20150330_083512.dat	2015-03-30 16:52	DAT File	15 618 KB
DataLogger_20150331_085039.dat	2015-03-31 21:31	DAT File	23 899 KB

Figure 6 Some examples for the name of documented operations.

The recording step of the operations could be 0.005 or 0.05 second. So, the first step is to check the total frame of the recorded data, and then to calculate the length of the period and to add the times of the operations to verify that the measuring period is correct.

For example, there are totally 91314 frames on 31/03/2015. Which means 91315/20=4565.7 seconds. This is only around 1.3 hours, which does not seem to be correct. So, in this case, the recording step should not be 0.005 s. Then we can find that 91315/2=45657 seconds, which is around 13 hours. And the working period for the machine, based on particle counter measurements, is from 08:51: 02 to 21:31:22, which is totally around 13 hour. This verifies that the recording step was 0.05 s. So, from this simple calculation, it is easy to find the right measuring step for each day.

3.3 Analysis of the machine breaks

In the real work, there are to situations that have to be considered. One is that the machine has been stopped for some reason, and the other one is that it has been settled down but not stopped. Usually, the first situation means that some machine component is broken, and the operator has to stop the machine and repair/replace it. These kinds of problems do not happen very often. Shown in table 2, is a list of all the maintenance of the machine from the day it starts to work and until the field test was completed.

The table was recorded in Swedish, so “Google translate” was used to translate all the words and sentences. Since some of the reasons are translated in a strange way, the sentences have been reformulated a little bit.

The questions marks shown in table 2 means the operator has not found the broken machine component, so they just refilled the tank and started the machine again. There are three main reasons for turning off the machine: plug leakage, broken hose, or oil filling, which all relate to the hydraulic system.

Table 2 The reasons for stop the machine

Date	**Lasting Time**	**Liter**	**Clock time**	**Reason**
2014.11. 26	157	20	11:00	Plug leaks right under the stairs of a valve.
2014.12. 03	213	20	10:00	Plug the left unsealed otherwise as above.
2014.12.06	240	20	14:00	Leaking shit plug
2014.12.08	255	15	17:00	All kit plugs were removed and glued.
2014.12.11	293	5	14:00	Adapt spray knife broke.
2015.01.13	433	20	06:00	??????
2015.01.14	445	30	10:00	Hose to measuring points apart frayed (unit pump).
2015.01.28	558	20	10:00	Pressure hose into the unit, 1 '.
2015.01.29	569	10	06:00	??????
2015.02.23	770	20	18:00	Stir in the cabin wall screwed up.
2015.03.02	825	20	17:30	The pressure hose again, crap construction.
2015.03.17	934	20	08:30	Hose feed roller
2015.03.31	1053	40	11:00	Slang for stairs
2015.04.08	1100		12:20	Pressure hose assemblies, third shit.
2015.04.08	1103		15:30	Replacing pressure hose
2015.04.09	1115	20	14:00	Oil Filling

The second situation is the record of machine breaks for more than five minutes. The application *OpMon* was used to read the files that contained records for the machine breaks. The application GUI is shown in figure 7. On the upper left corner in the application window, the driver can be selected. Since, whoever drives the machine is not expected to have a big effect on the breaks, the “All operators” should be selected. On the main part of the GUI window, is indicated the starting time of the break indicated and the counted total period of the break (the unit for time is s). The type code and specification code has not been used in the present analysis.

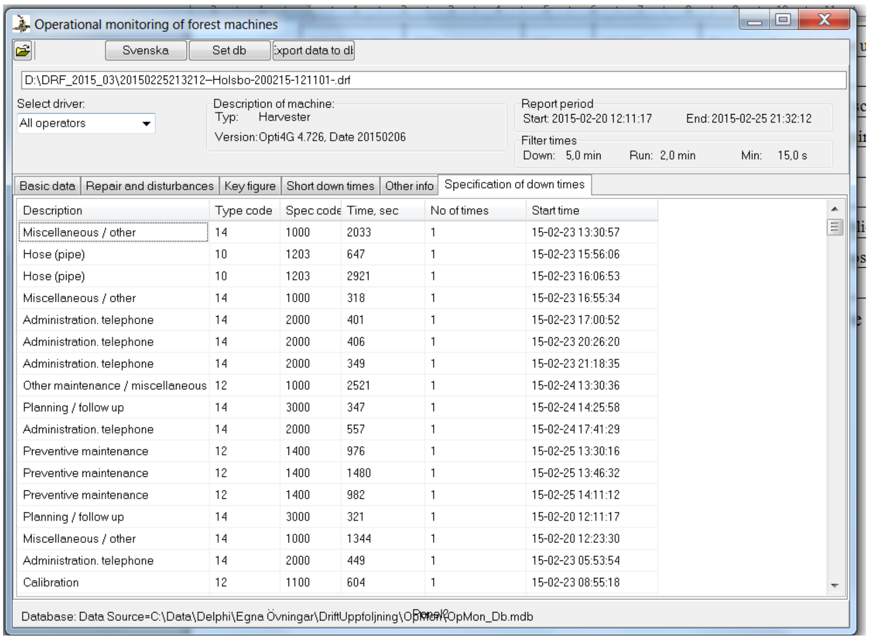


Figure 7 Application for recording the machine breaks

There are many factors which may cause a machine break that will last for more than five minutes. The most common reasons are: Calibration and Preventive maintenance, which will happen at least twice a day. Then Hose (pipe), Miscellaneous/other, Refilling and lubrication, and Fuel system means some components of machine require some adjustment to be made. There are also some other reasons for a machine break, like Administration telephone or Planning. When these kind of breaks happen, it means the operator did not adjust any part of the machine, they just made a phone call or made a rough schedule for next week’s work. Besides, the Ordered stop in this application has two meanings, one is that some other student who is also included in this forest machine project interrupted the normal machine operation for a specific test. So the measurements were stopped for a while. And the other one is Unknown but regular stops; they stopped the machine for some commercial reasons.

3.4 Analysis of Particle counter

As introduced in chapter 2, the amount of particles was continuously measured. So, it is important to analyze the changes in the data. Run the Matlab code in Appendix A, and then the plots for each day’s data will turn up. Figure 8 presents some example plots of a whole day’s stored data.

In the illustration, there are totally five lines with different colors. The blue line represents particles with a size of 4μm. Their average value is around 15 (per 100 milliliters). Particles which are as large as 6μm are represented with an orange line, and their amount had usually a value of 5 (per 100 milliliters). The colors for the14μm- and 30μm-particles are yellow and purple, respectively. These larger particles usually keep a value of 0, until the 4μm and 6μm particles get into a peak value. Then they will also reach a peak value but their amount is much smaller than the amount of 4μm particles. The green line shows the relative humidity of the fluid. As mentioned before, there were usually some breaks during the day. The peak values appeared after the breaks.

After comparing the data from different days, two assumptions were made. Firstly, check the step time. Since the step time between each measurement were set one 1, the total step time should be in the range from 800 to 900 minutes, if the machine was operated normally for the whole day and the operator just had made some regular adjustments. If the total step time is much less that quantitative value, there could be two reasons to that. One is that the operator usually finishes the job earlier on Friday or the last day before holiday, than the other workdays. The other reason is that some of the elements were broken and the operator had to do some maintenance. For the second reason, it is necessary to check the variation of the data before the break, and try to figure out whether or not this kind of data could be used as a prediction for required machine maintenance.

From the same day, it is easy to find, that, in most cases, the peak value of 4μm particle is 40 (per 100 mL) and it usually appear individually, and the amount of particles will be reduced in 1 step time to the normal value.

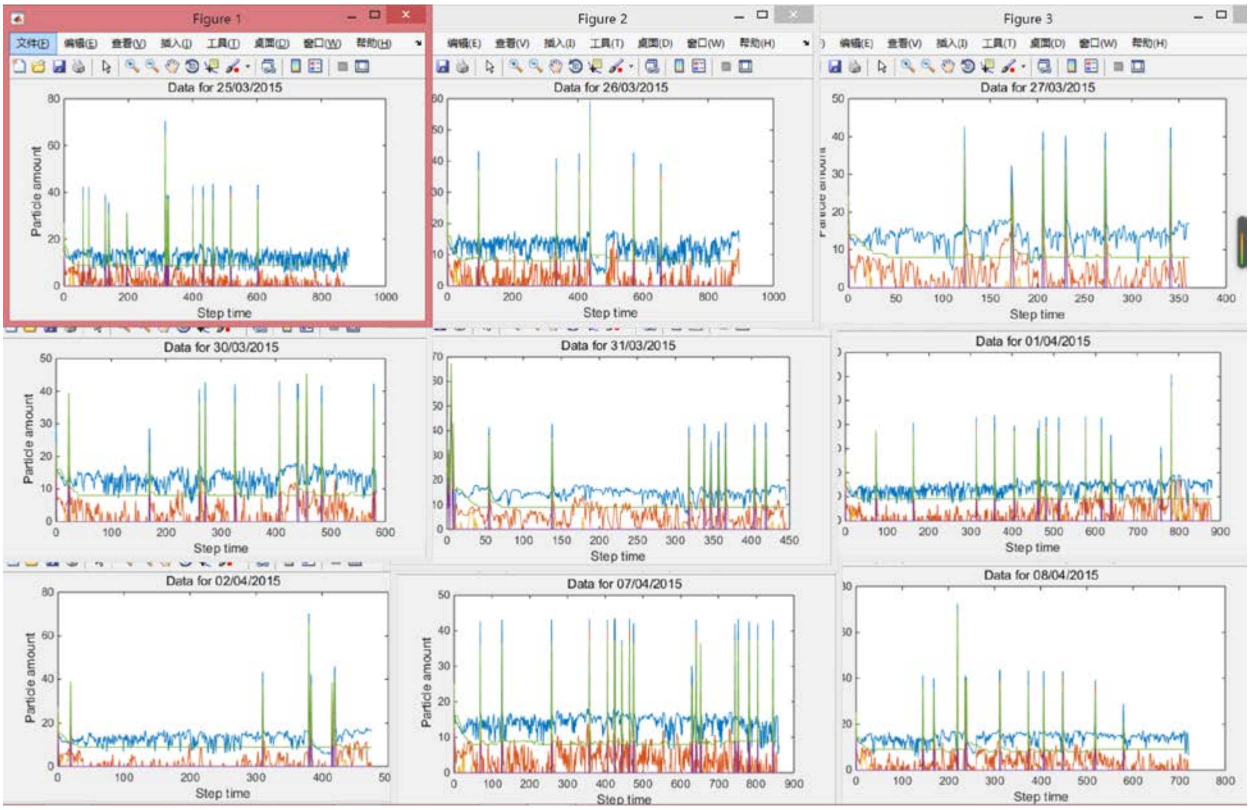


Figure 8 Some example plots for the particle measurement.

3.5 Analysis of Each Assumption

Based on an analysis of each method, some assumptions could be formulated. These assumptions are introduced in this section.

3.5.1 Assumption 1-The connection between operations and particle counter

When the assumption for the operations that may influence the particle count was made, the task was to search for the relation between them. The analysis could be performed from two sides. Usually the shifting operations happened in a short time, like a few seconds or few minutes. So, breaks less in five minutes were chosen for this analysis. The first part of the analysis was identifying all the breaks and then to find the machine operations to see if there was any pattern between these two factors. Then, the other part was the antithesis, the shifting period of the operations should be chosen and then the relative particle counting period should be found. So the useful operations should be plotted, making it much easier to find the shifting period and the operating process could be defined.

Below is a plot of the data from 2015-03-27, which is an example of a day with no maintenance breaks. The data collected from this day can also be found in Appendix C. In the figure, there are totally four breaks less than five minutes. These breaks have been listed and counted into relative frames in Tiwalde. Since there are too many operations that are required for the analysis, only two of them have been chosen here as examples. One is the "Valve, swing left" and the other one is "Frame steering valve, left".

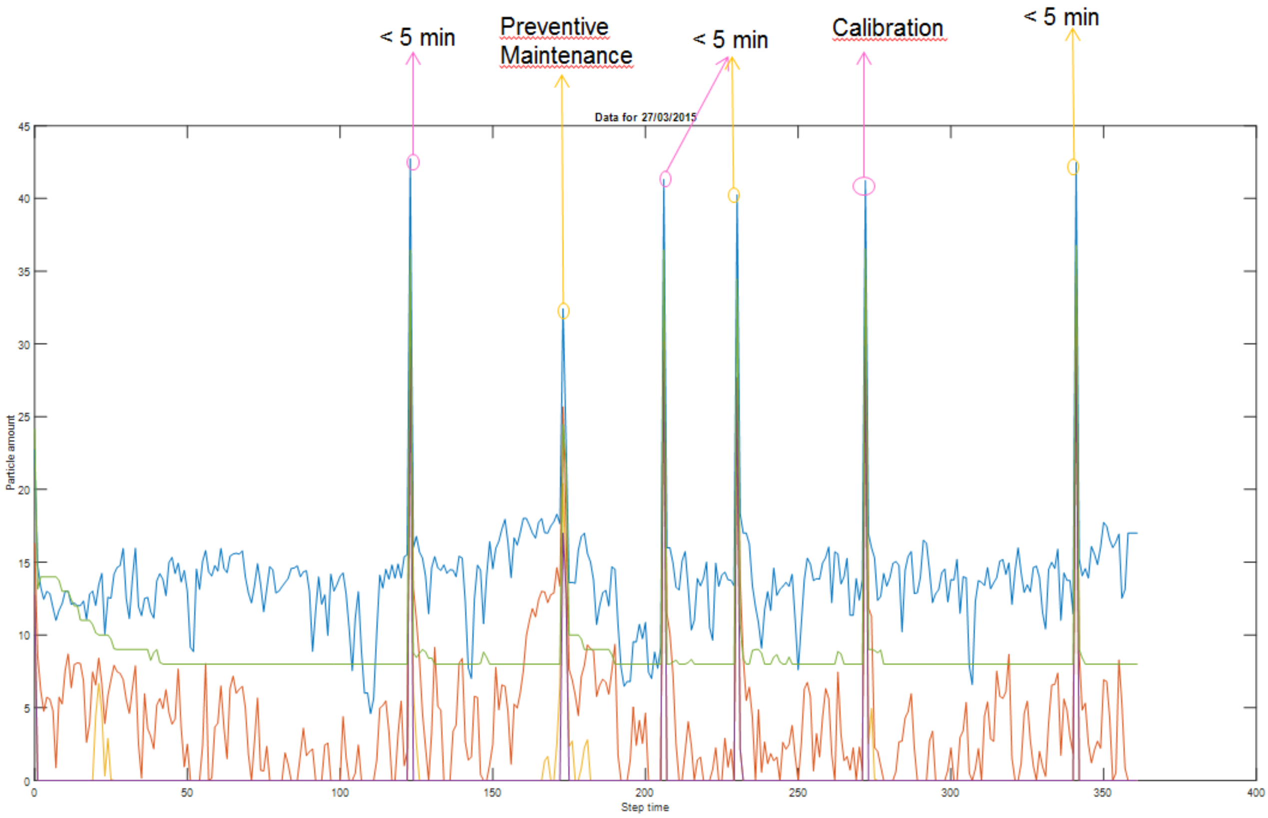


Figure 9 Measured data on 27/03/2015

07:54:28 – 07:57:35 Frame: 14703 – 15077

10:16:03 – 10:18:20 Frame: 31573 – 31847

10:41:21 – 10:44:19 Frame: 34609 – 34965

12:39:43 – 12:42:02 Frame: 48813 – 49091

After q conversion between wall clock time and measuring period for the operations, the relative operation status for that period was analyzed. The following two plots show the movements of "Valve, swing left" and "Frame steering valve, left".

From these figures, it is hard to find a distinct pattern between the operations and particle fluctuation. On the figure for "Valve, swing left", the value of the operation is 0 during a break time, which means it is not activated. The vale could be swinging right or not being activated.

But on the contrary, when the valve is not indicating “swing left”, this does not necessarily mean that the value of the particles has increased.

Besides, the item “Frame steering valve, left” has a different situation than the operation for “Valve, swing left”. From the figure, within the breaking time, the movement of the frame steering valve could be in any situation. It could work continuously, it could totally not work, or it could also shift from working to a motionless state.

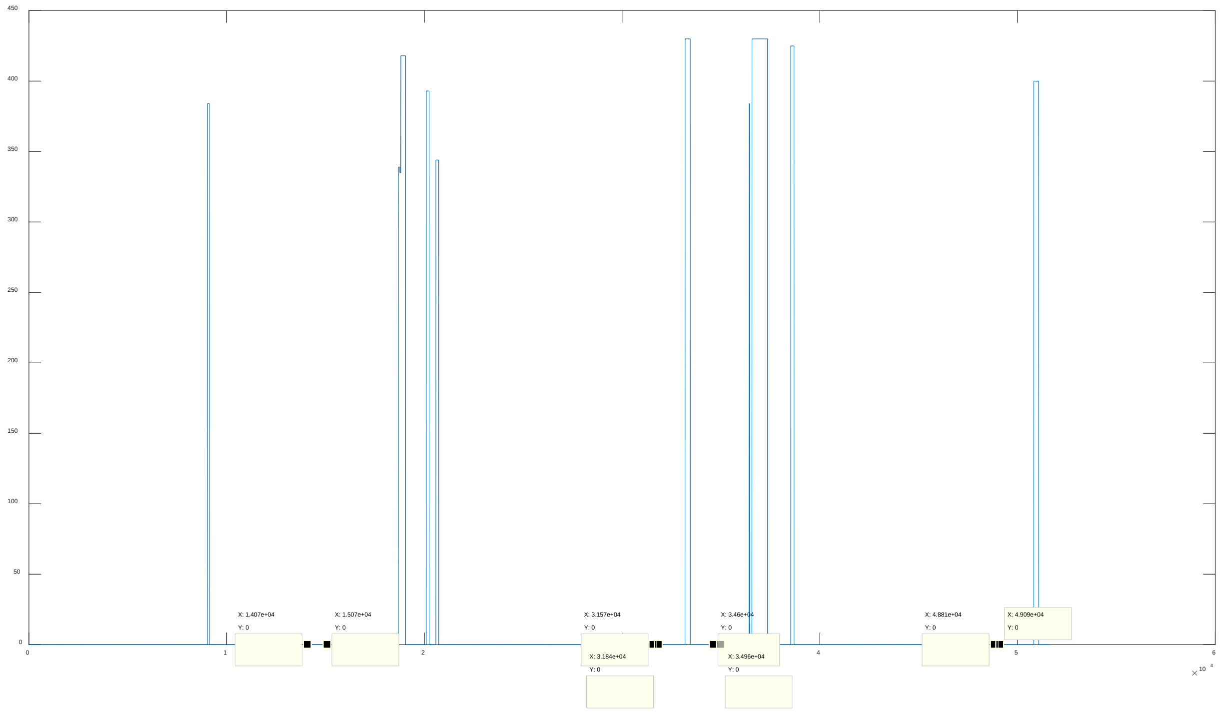


Figure 10 Plot for “Valve, swing left”, with marks for breaks less than five minutes

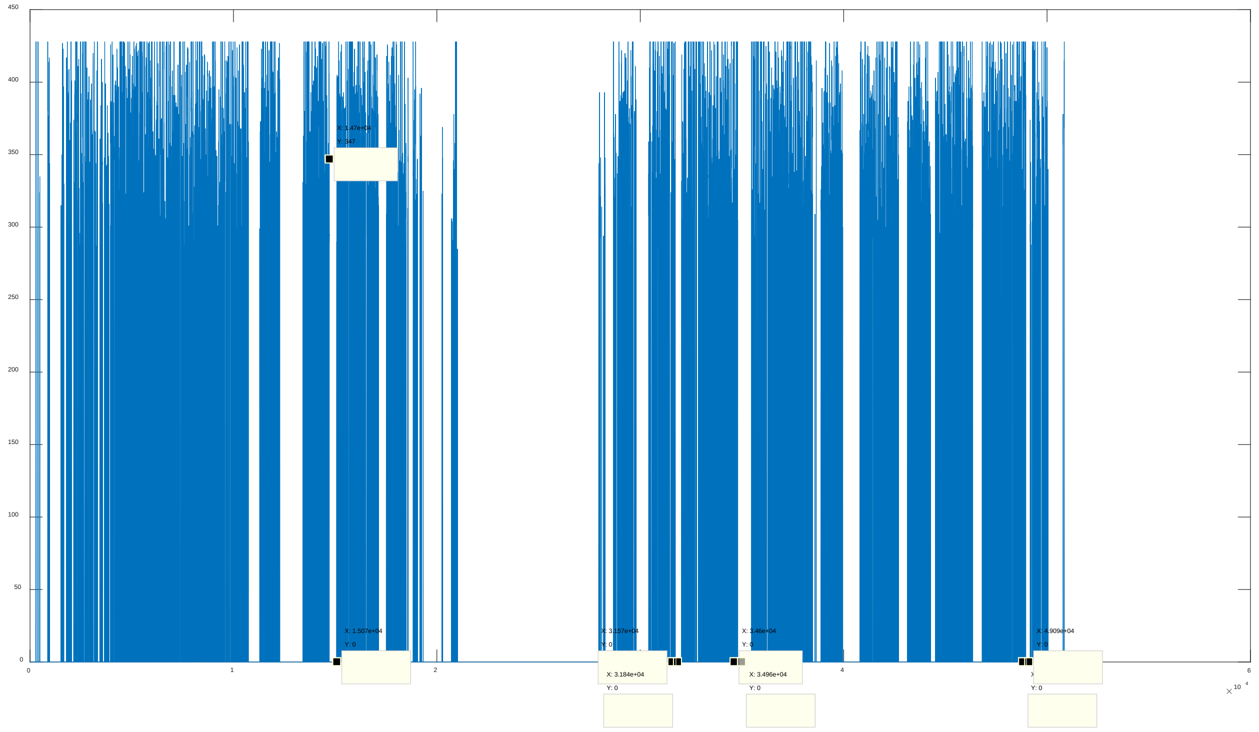


Figure 11 Plot for “Frame steering valve, left”, with marks for breaks less than five minutes

From these two previous figures, it is difficult to say whether or not the machine operations could have influenced the particle counting system. From the other side, as shown in appendix C, sometimes during the normal working process, the value of the 14μm-particles did suddenly increase in a short time. All these "special" values have been chosen from the measured data and all these values, the relative frame number for machine operations, and the some note including the previous action of the machine, or the reason for choosing these factors, are presented in table 3.

Table 3 Summary of the data chosen for the analysis

Time	**Frame**	**Note**
06:12:24 – 06:16:24	2455 – 2935	"14μm" become larger
07: 57:35 – 07:59:35	15077 – 15317	3-minutes-break
08:41:37 – 08:42:37	20361 – 20481	"14μm" become larger
08:45:37 – 08:46:37	20841 – 20961	"14μm" become larger
09:44:02 – 09:47:02	27851 – 28211	Preventive maintenance
09:50:02 – 09:52:02	28571 -- 28691	"14μm" become larger
10:18:20	31847	2-minutes-break
10:44:19 – 10:45: 19	34965 – 35085	2-minutes-break
11:31:40 – 11:34:40	40647 – 41007	Calibration
12:42:02	49091	2-minutes-break

Based on these values, the relative working statement of a specified component could be seen in the next two figures. Figure 12 shows the situation for "Valve, swing left" and figure 13 presents "Frame steering valve, left".

The conclusion that can be made, based on these two figures, is the same as the previous conclusion. The changing pattern of the 14μm-particles could not be used to find the related machine operations. The next step is to analyze the machine operations, try to find the shifting point of each operation, and then to do a conversion of the shifting time and to compare the changing pattern of the measured particle values.

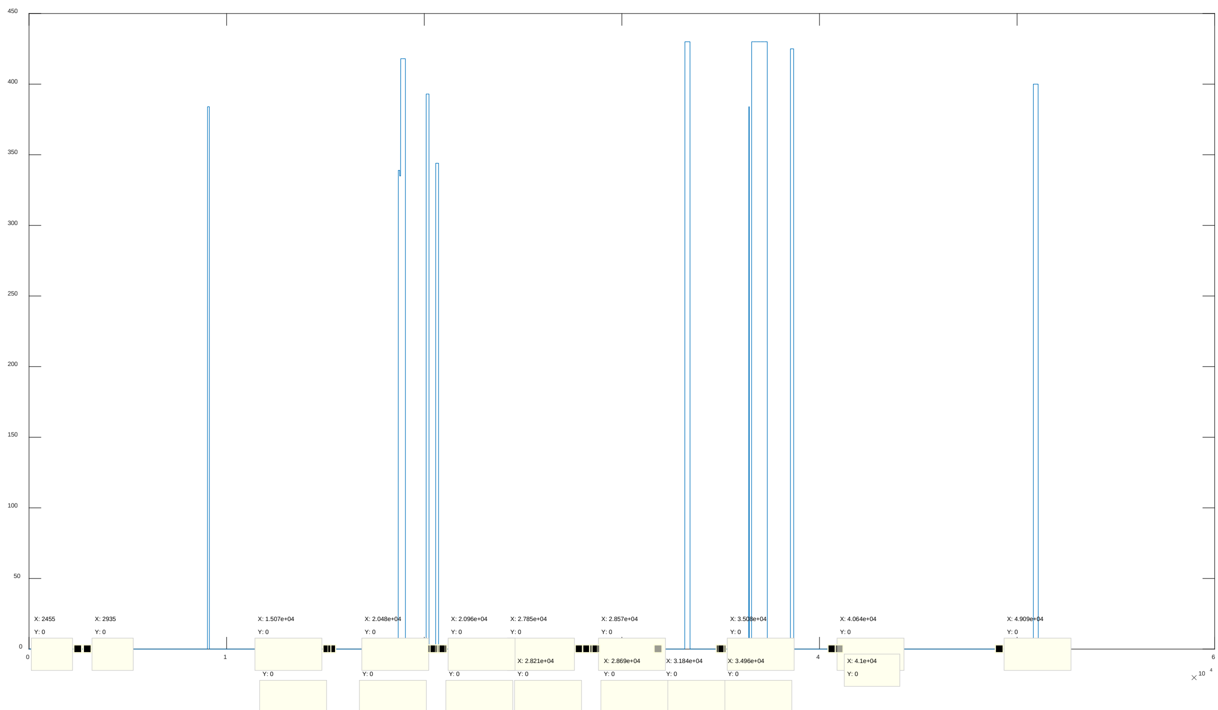


Figure 12 Plot for "Valve, swing left", with marks for special values

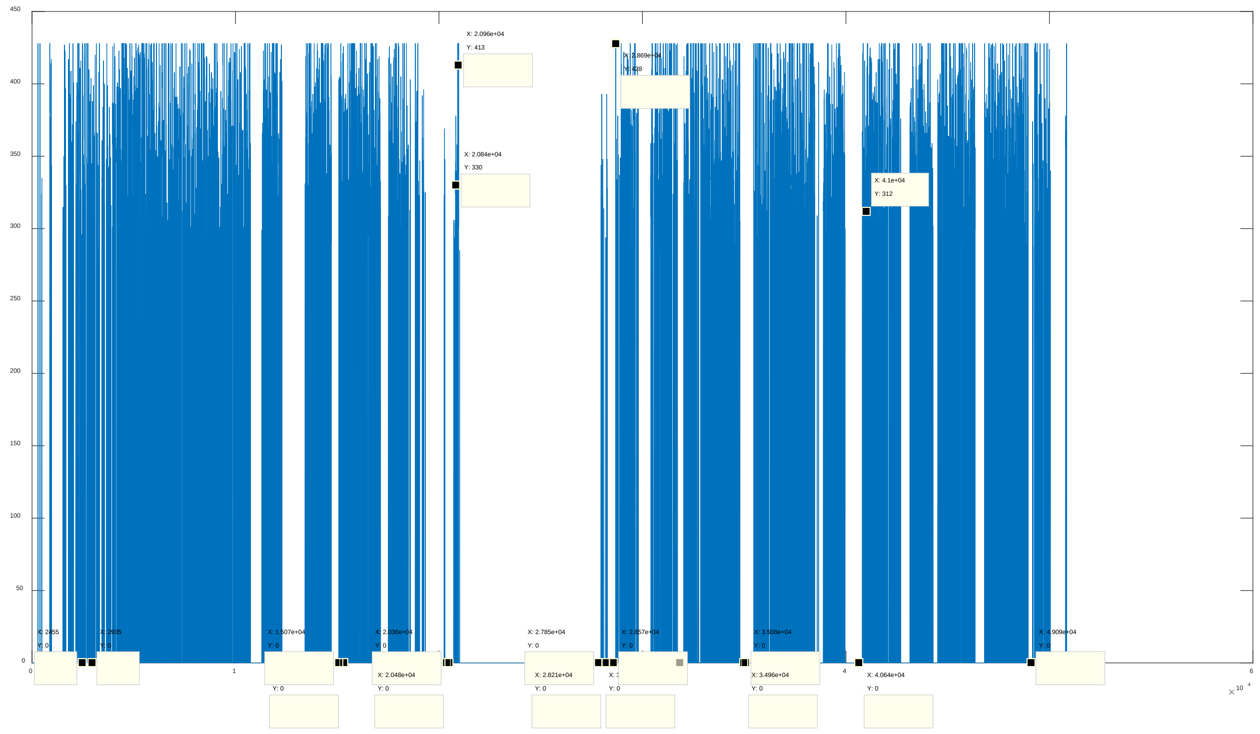


Figure 13 Plot for “Frame steering valve, left”, with marks for special values

As can be seen in the plots, the regular valve and the frame steering valve have different working patterns. The regular valve starts to work randomly and it shifts back within a few seconds. The frame steering valve usually remains at a working state. So, based on their situations, the working period of them was chosen as follows. Both of the valves were shifted, and the working period were chosen based on their response plots, and then all these points were converted into relative time, which was used to check the measured particle values.

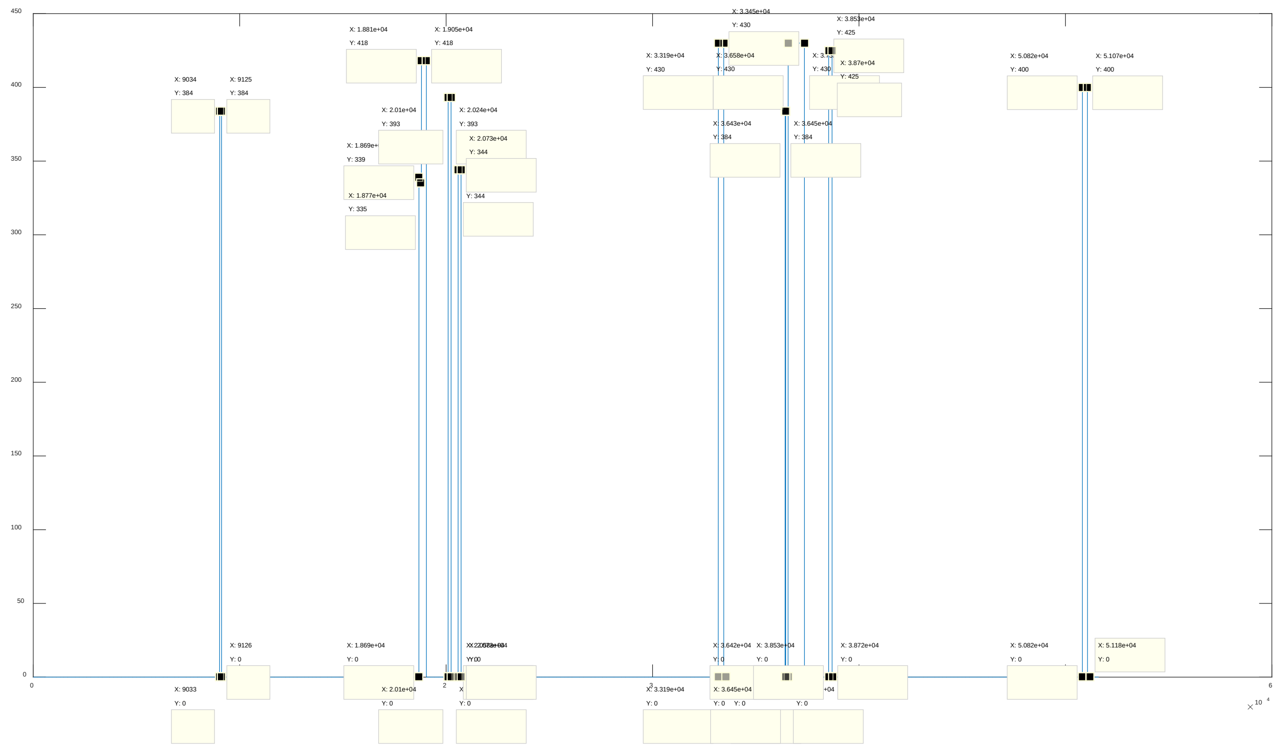


Figure 14 Plot for “Valve, swing left”, with shifting points

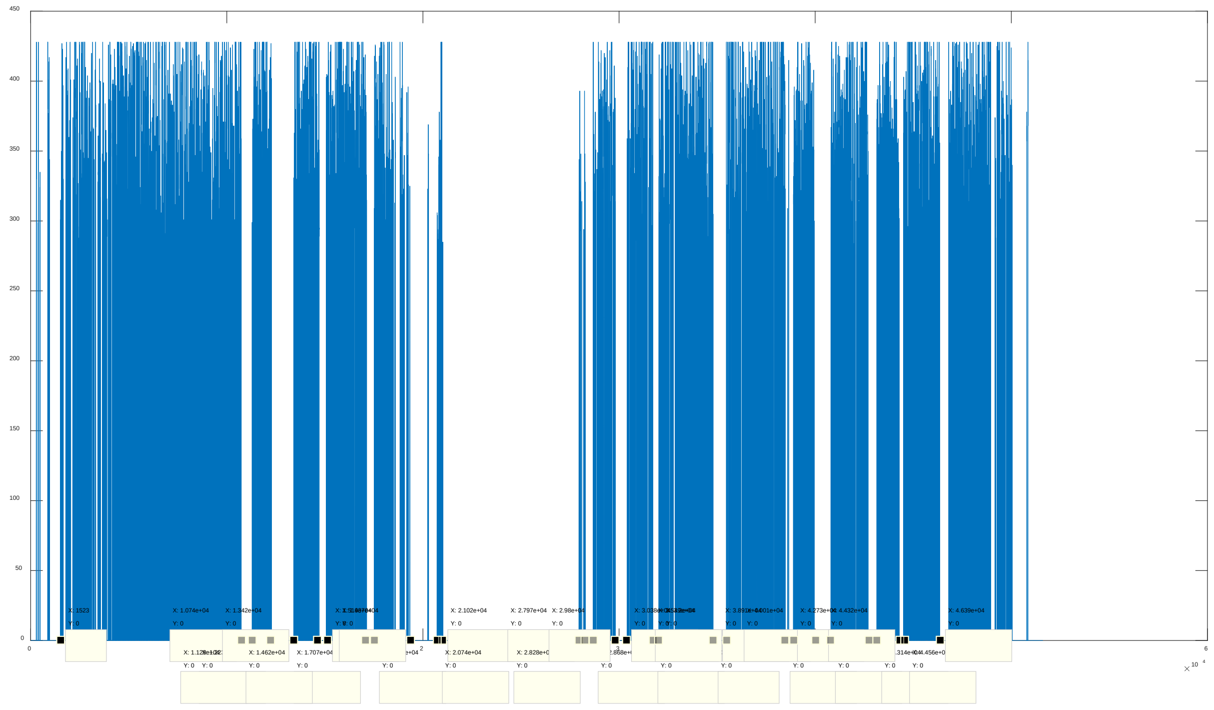


Figure 15 Plot for “Frame steering valve, left”, with shifting points

From the shifting process, it is quite easy to find that the amount of particles for each particle size could be have any value. For example, during the working period of the frame steering valve, the measured value of 4µm-particles could be at an average value, smaller value, or larger value. Besides, during a longer working period, the value of 4µm-particles could first decrease and then return to the normal value.

Not only these two operations, but also the other operations show the same situation. The author picked data for 10 days, which included both the recorded particle count and the document of the machine operations, and then performed the same kind of analysis for all the chosen operations. All analysess and comparisons showed the same results.

Then, to think from the real operation of the machine, several components should be active at the same time, and the influences from the different operations might be counteracted or enhanced. In the author’s opinion, the future work based on this thesis should be bonding the operations of the machine and to figure out if there are any influences between the combination of operations and the amount of particles.

3.5.2 Assumption 2-The use of first measurement of particle counter

After the data from the IcountPDR was gathered and compared, it was easy to find that the first step of the measurement always had a larger than average value but smaller than the other peak values. The first measurement from each day of the field test was imported to Excel, as seen in figure 16. The average value of each measuring item is also presented in the figure. Based on the average values, the values which are out of the range were identified and colored in red.

Mon	Mar	2	9:58:48	2015	57	1	10.966667	8.233333	5.983333	0	12
Tue	Mar	3	5:46:14	2015	36.55	0.95	26.033333	19.75	12.75	12.75	27.95
Wed	Mar	4	5:19:39	2015	39.216667	0.95	26.416667	20.233333	12.75	12.75	29.15
Thu	Mar	5	5:20:11	2015	39.75	0.95	27.6	20.35	14.2	12.75	29.45
Fri	Mar	6	5:17:56	2015	15.216667	0.95	21.45	15.433333	12.75	12.75	27
Mon	Mar	9	4:38:59	2015	10.416667	0.95	20.066667	13.383333	13.2	12.75	27.95
Tue	Mar	10	5:17:43	2015	13.083333	0.95	20.95	16.083333	12.75	12.75	27
Wed	Mar	11	5:26:25	2015	24.283333	0.95	23.516667	16.616667	12.75	12.75	26.866667
Thu	Mar	12	5:47:23	2015	15.95	0.883333	50.35	45.466667	42.55	42.55	55.083333
Fri	Mar	13	5:49:19	2015	25.616667	0.95	22.833333	16.383333	15.183333	12.75	27.95
Mon	Mar	16	5:17:17	2015	49.883333	0.95	27.516667	20.6	12.75	12.75	28.95
Tue	Mar	17	8:15:36	2015	54.15	0.95	28.9	23.2	17.866667	12.75	27.183333
Wed	Mar	18	5:17:47	2015	39.216667	0.95	26.683333	20.366667	12.75	12.75	27.866667
Thu	Mar	19	5:18:50	2015	45.083333	0.95	27.433333	20.65	12.75	12.75	27.55
Fri	Mar	20	5:24:24	2015	36.016667	0.95	26.266667	19.166667	12.75	12.75	26.6
Mon	Mar	23	5:53:26	2015	9.35	0.95	19.883333	12.916667	12.833333	12.75	26.05
Tue	Mar	24	4:40:05	2015	30.15	0.95	23.633333	16.983333	12.75	12.75	26.05
Wed	Mar	25	5:31:09	2015	20.816667	0.95	17.55	15.283333	14.366667	12.75	27
Thu	Mar	26	5:24:03	2015	26.15	0.95	21.216667	15.5	14.666667	12.75	26.05
Fri	Mar	27	5:52:23	2015	25.083333	0.95	22.716667	16.3	12.75	12.75	24.15
Mon	Mar	30	5:28:43	2015	54.15	0.95	28.666667	21.65	12.75	12.75	24.3
Tue	Mar	31	8:51:02	2015	8.55	0.95	12.75	12.75	12.75	12.75	25.1
Wed	Apr	1	5:27:01	2015	54.15	0.95	28.133333	21.883333	14	12.75	27.283333
Thu	Apr	2	5:25:24	2015	46.683333	0.95	27.533333	20.75	12.75	12.75	26.666667
Tue	Apr	7	5:46:39	2015	15.75	0.95	19.666667	13.85	13.516667	12.75	25.1
Wed	Apr	8	5:01:32	2015	22.416667	0.95	19.366667	15.8	12.75	12.75	24.933333
Thu	Apr	9	5:45:35	2015	27.216667	0.95	23.266667	16.816667	12.75	12.75	25.1
Fri	Apr	10	5:36:23	2015	26.416667	0.95	35.616667	31.866667	29.35	27.683333	38.516667
Mon	Apr	13	5:26:35	2015	54.15	0.95	28.266667	21.883333	16.25	12.75	25.283333
Tue	Apr	14	5:25:17	2015	45.616667	0.95	27.7	20.65	12.75	12.75	26.683333
Wed	Apr	15	5:25:26	2015	43.483333	0.95	27.666667	20.383333	12.75	12.75	26.3
Thu	Apr	16	5:26:44	2015	41.35	0.95	27.6	20.5	12.75	12.75	25.916667
Fri	Apr	17	5:24:57	2015	26.683333	0.95	23.1	16.433333	12.75	12.75	25.1

Average Value

4µm: 24.8

6µm: 19

14µm: 14.5

30µm: 13.7

Humidity: 28

Figure 16 The first step measurement for each work day

From the table in figure 16, totally four days were chosen. Firstly, from the fourth column, the clock time express the starting time for each workday. From the time, we could find that the measurements started from the mid of the day on 2015-03-02. The data from that day could not be used for the analysis. The measurements on 2015-03-12 and 2015-04-10 started on time, as usual. Then the tests started a little bit late because of a machine maintenance on 2015-03-31.

Then the following figure has shown the situation of date 2015-03-12. The reasons for each break are listed in the figure 17. During the whole day, maintenance of the pipe as performed and there is also a break referred to as *Miscellaneous/Other*, which also means the machine was serviced for some mixed problem.

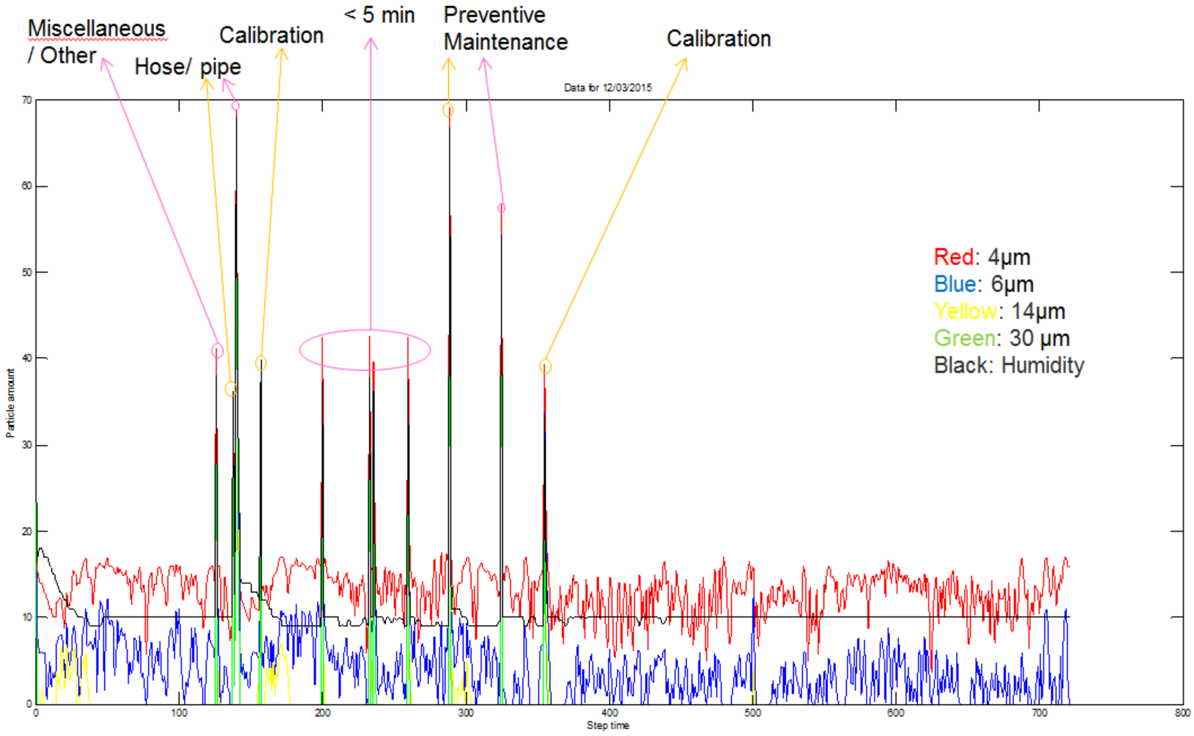


Figure 17 The plot for date 2015-03-12

Figure 18 shows the recorded data for 2015-03-31. At the beginning, the *Hose/Pipe* was broken, so the operator had to spend almost two hours to fix it. After that, from the curves in figure, the machine was in operation again.

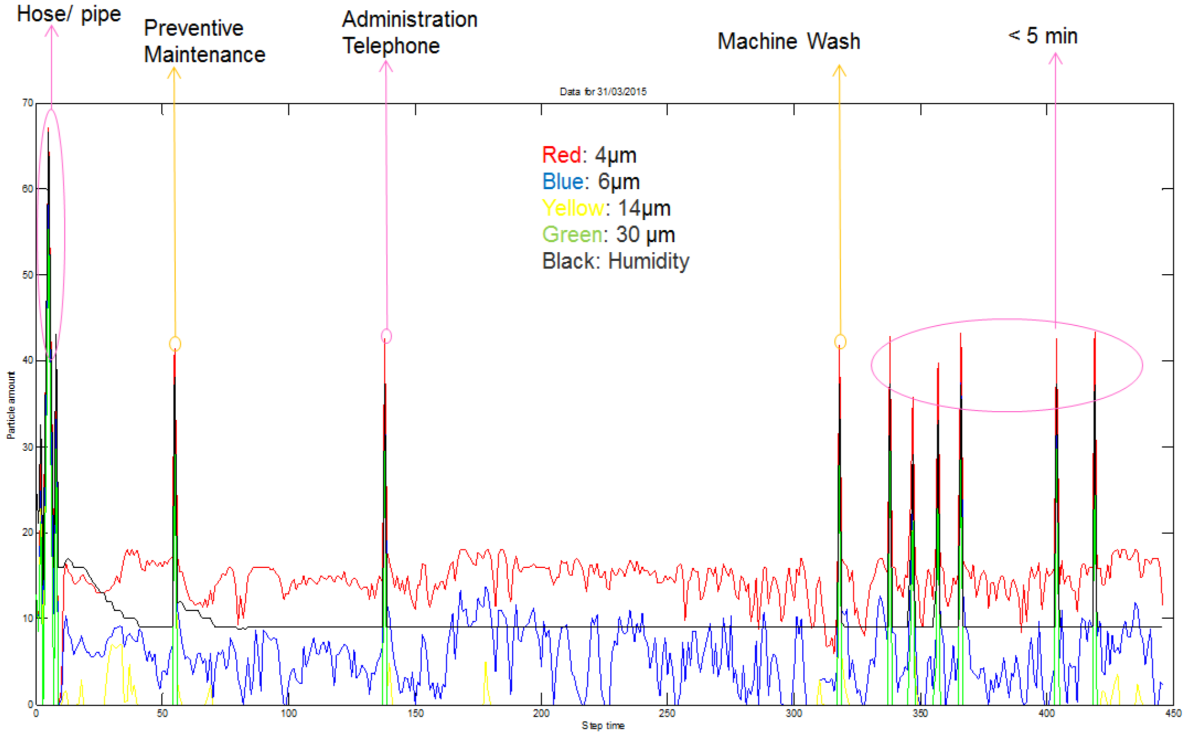


Figure 18 The plot for date 2015-03-31

The field test lasted for around two weeks and the breaks of machine were recorded during period from 2015-02-25 to 2015-04-07, so the data for 2015-04-10 is missing. The plot for this day shows several problems. The measurements started normally until a break around the 200th step time. During 200 to 250 step time, there must have been some machine problem, making the operator to settle down the machine many times. It is easily observed that the red, blue, and yellow lines disappeared in that period. In a normal situation, the 4µm particles should vave the largest value and the 30µm particles should have the smallest value, but on the contrary here, the 30µm particle has the largest value and the smaller particles are all close to zero. This phenomenon was also found which for 2015-03-31.

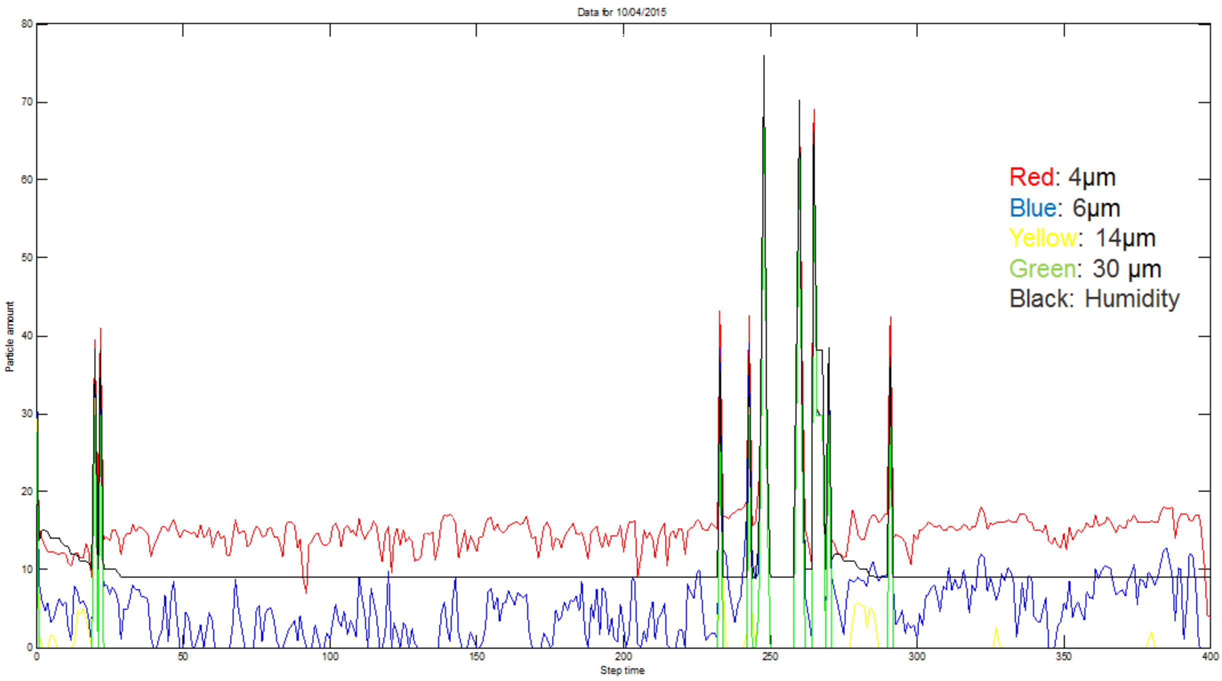


Figure 19 The plot for date 2015-04-10

If we compare the data collected on 2015-03-13, as shown in next figure, with the data from 2015-04-10, we can find some common details. From 175 step time, all the particles changed to zero except for the peaks shown in the figure. Just after the breaks they have the same value, which seems not right.

During this irregular period, the machine was at maintenance for a long time, until the measurement values returned back to normal values. After the maintenance, the operator stopped the machine and started it after the weekend, then the machine was working normally and all the recorded data turned back to their “right” levels.

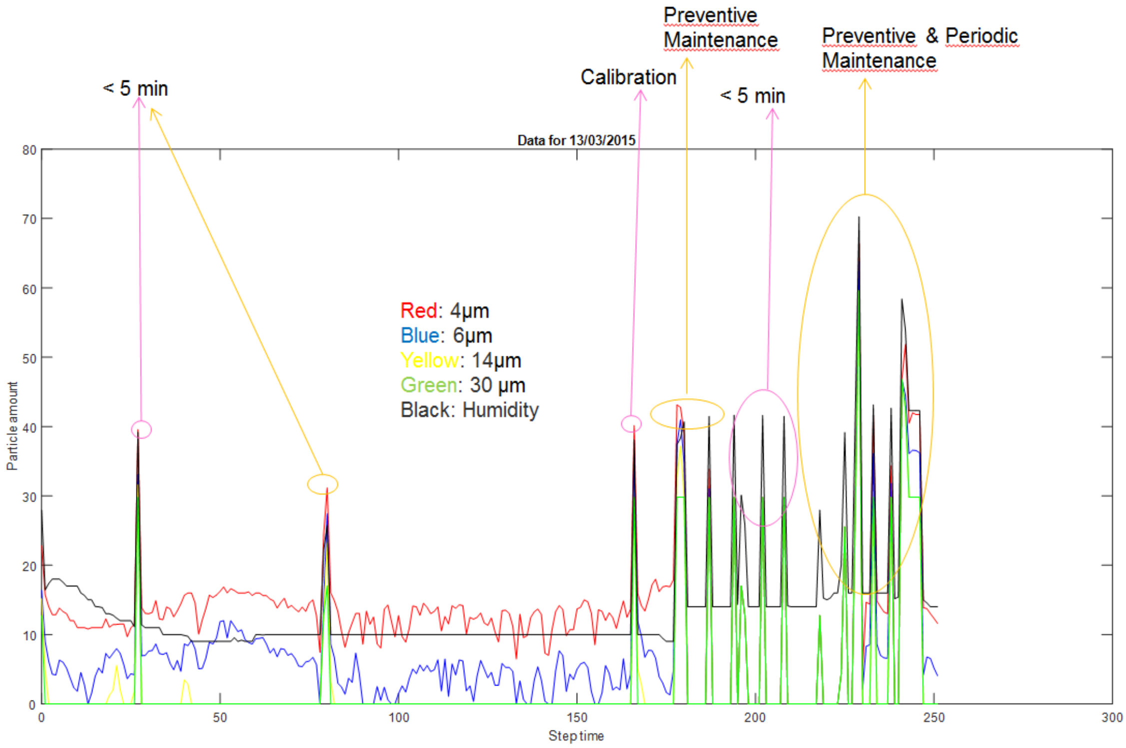


Figure 20 The plot for date 2015-03-13

There are only three days' data that could be used to do the analysis. It is difficult to say whether or not the first measurement of particles could be used to predict a need for machine maintenance. The conclusions from this analysis could be summarized as follows:

- The first particle measurement might be used to predict the machine maintenance, but more data is required, so a longer field test should be performed.
- Even if the first measurement of the particles could be used, it could, however, be any component in the system that will fail. It could be a broken Hose/pipe, Miscellaneous/other reason, or some other problem that require a long time repair.
- The repair breaks that occur not necessarily mean that the first value is out of the range.

3.5.3 Assumption 3-The comparison between each days' data

In order to compare the data from each day, the data for 4μm particles were chosen for the analysis. As seen in figure 21, there are basically three levels of the number of particles. The base level is around 10 (per 100 milliliters), and the second level is 40, which also is the value for most of the peaks. The third level is representative for some of the peaks with values over 40, almost 60, and even higher.

The number of third level occurances is much less than for the second level. If these peaks reach to a higher number after regular breaks, it might indicate a need for maintenance.

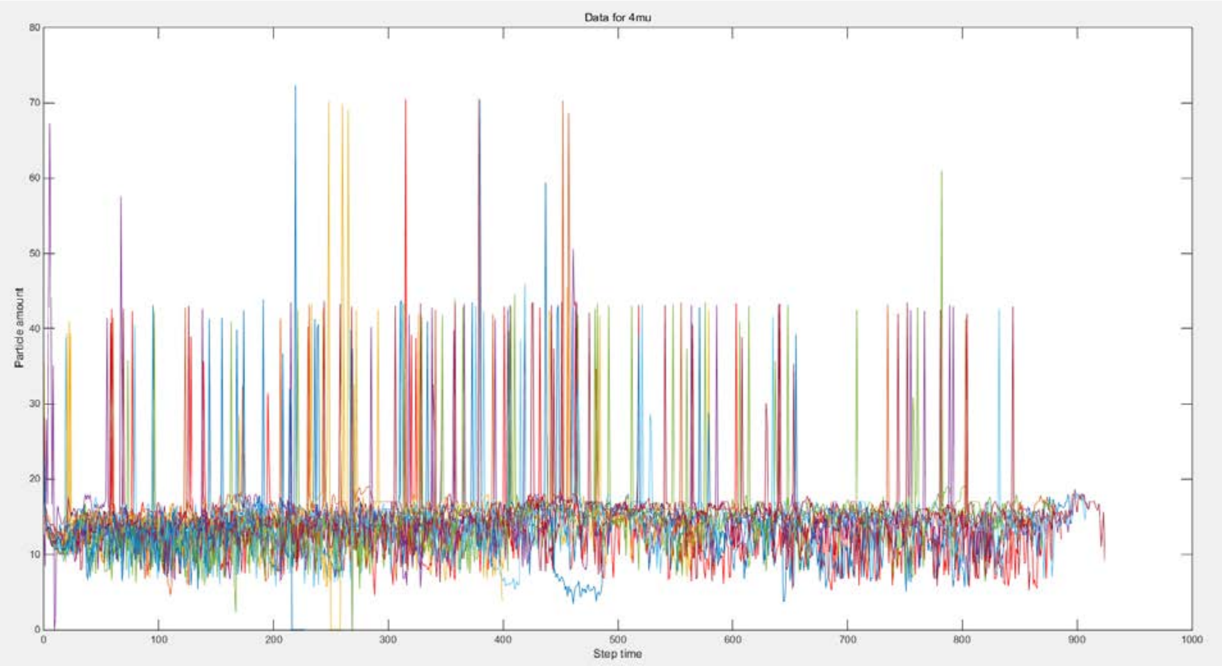


Figure 21 The plot for 4 μ m particles

In order to prove this assumption, it is necessary to summarize all the breaks during the field test, and the number of 4μm particles after regular breaks should be checked. So, the conclusive list would be:

02/03: Ordered Stop (Over 60); Hose (Pipe)

03/03: Hose (Pipe); Planning (Between 40 and 60)

04/03: All around 40; No fixing

05/03: Normal Value (Over 60); Preventive maintenance (Over 60); Miscellaneous/ Other maintenance

06/03: Normal Value; Short break (Over 60); No fixing

09/03: Normal Value; Preventive maintenance (Over 60); Short break (Over 60); No fixing

11/03: All around 40; No fixing

12/03: Miscellaneous/ Other; Hose (Pipe) (Over 60); Normal Value; Preventive maintenance (Over 60)

13/03: Normal Value; Continuous peak values (Preventive maintenance); Sort break (Over 60); Preventive maintenance (Achieve 60)

16/03: Normal Value; Preventive maintenance (Over 60); Later Hose (Pipe)

17/03: At the beginning (Measurement has not been started); Hose (Pipe); Normal Values

18/03: Normal Value; Preventive maintenance (Over 60); No fixing

19/03: Normal Value; Administration Telephone (Over 60); No fixing

20/03: Normal Value; Miscellaneous/ Other; Refilling and Lubrication; Preventive maintenance (Over 60)

23/03: Normal Value; Short break (Over 60); No fixing

24/03: All around 40; No fixing

25/03: Normal Value; Preventive maintenance (Over 60); No fixing

26/03: Normal Value; Preventive maintenance (Reach 60); No fixing

27/03: All around 40; No fixing

30/03: All around 40; After stopped the machine (Valves)

31/03: At the beginning (Hose (Pipe) (Over 60)); Keep fixing & all around 40; No more fixing

01/04: Normal Value; At the end (Achieve 60)

02/04: Normal Value; Preventive maintenance (Over 60); No fixing

07/04: All around 40; No fixing

The upper list includes all the breaks which led high peak value. Based on the available test information, some of the results could be summarized. Basically, it is hard to deduce the cause for the peak values. But from the available data, some speculative hypotheses could be formulated:

- The peak values appear randomly.
- If peak values are all around 40, then it means everything is fine.
- The higher peak values could be used to predict problems, but it cannot indicate which component that is broken

It is hard to decide whether a peak value 60 could be used as prediction of failure, or not. Because in the early stage of the field test, there was always maintenance following a particle peak value of 60. But in the later stages, maintenance sometimes took place several days after the time when the peak value reached 60.It would be better if the operator could check the status of the hydraulic components when a peak value of 60 was identified after a normal break.

3.5.4 Assumption 4-The combination of all irregular breaks

Since the previous assumptions could not predetermine the need for machine maintenance, it would beneficial if all the plots for the days when some component was adjusted could be compared and further analyzed.

For all days observed, there are three days that shows a significantly different behavior. Particle plots for these three days are presented and discussed below.

As discussed in the previous chapter, during the daily work, the number of 16μm-particles was usually zero (per 100 milliliter) and it reached a higher value in the first step measurement after each break. In the plot from the date 2015-03-02, the 14μm-particles (yellow line) shows a scarce trend. During the working process, it kept a larger value, compared with the data from other days. And this situation remained for a few hours, and then later a hose or pipe was broken and had to be repaired. After the maintenance was finished, the measured data for the 16μm-particles returned to the “right” level.

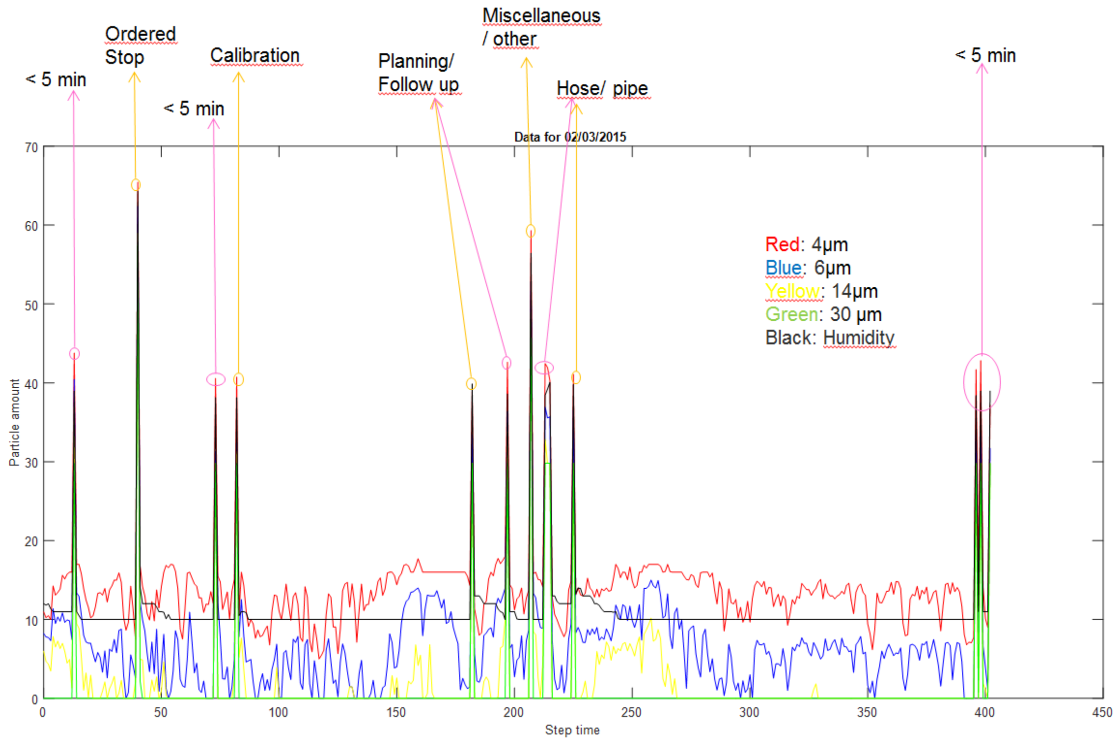


Figure 22 Measured data on date 2015-03-02

The next figure shows the collected data from 2015-03-09. There is no record of maintenance that day. In the plots, we can see that there are many small, less than five minutes, breaks, and most of the recorded values are normal. In this kind of situation, if the higher peak value which value is around 60 just appear once and the other peak values are around 40, and then there would, most likely, not be any problem for the machine. But, to verify this assumption, it would be good if the operator could check the machine when this situation is observed.

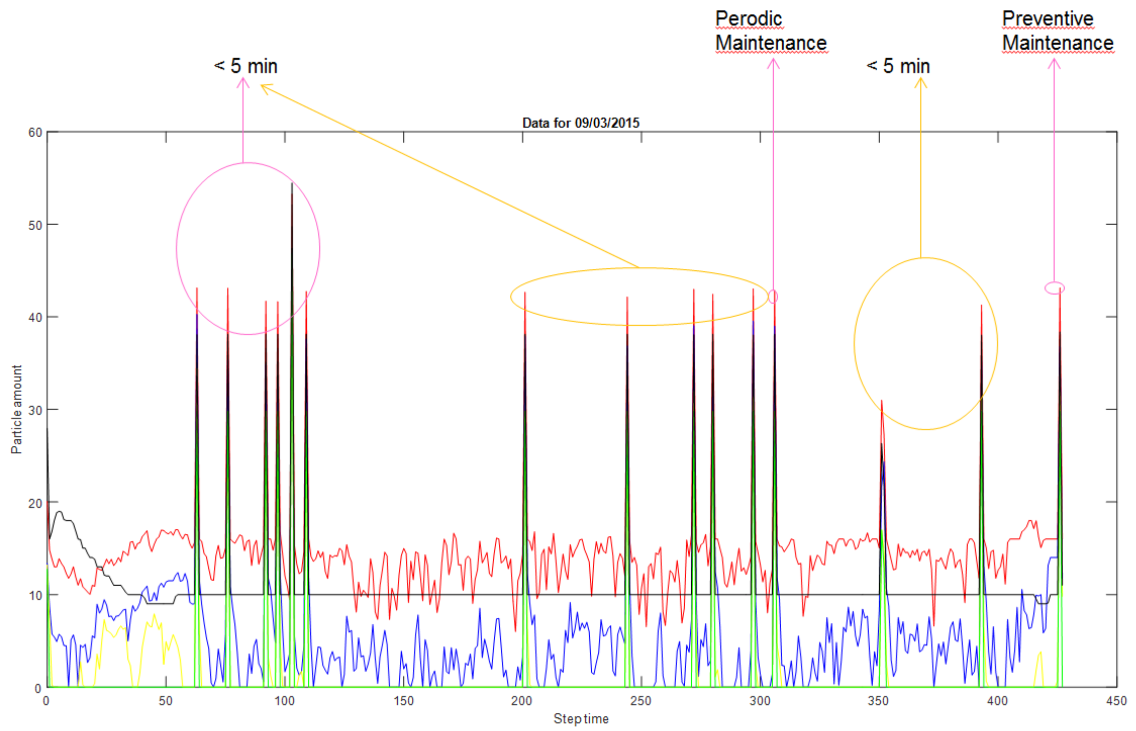


Figure 23 Measured data on date 2015-03-09

The last situation is about the use of the measured smaller particles. On 2015-3-13d, the number of both 4µm and 6µm-particles turned to zero, and then machine had to be maintained. In the author's opinion, if the data for both of them turn into zero after a normal break, it would be better if the driver could check the temperature of the system, and/or listen to the sound from the machine, and combine this with his/her experience, to try to identify the machine problem and fix it as soon as possible.

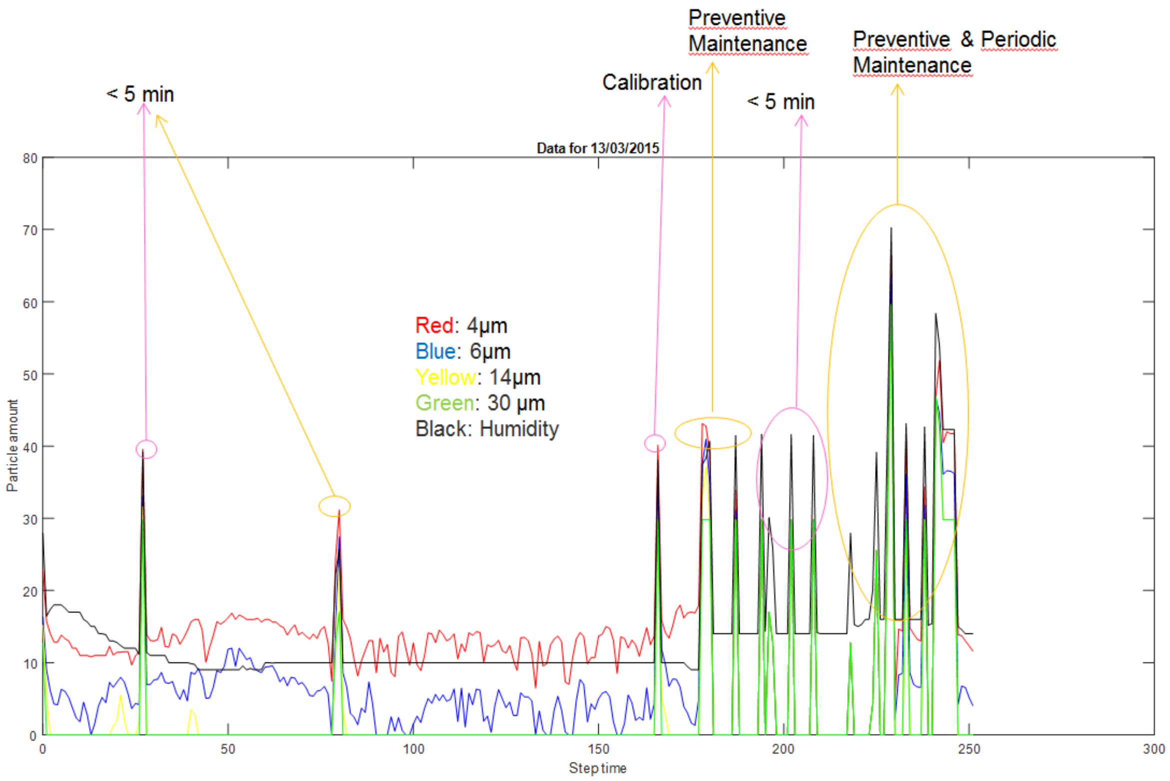


Figure 24 Measuring data on date 2015-03-13

Basically, 4µm-particles and 14µm-particles could be used to predict a need for machine maintenance. Usually the number of 4µm-particles will have a value around 10. If the value turns to zero, it probably means that the machine has got some problems and that the operator, consequently, should check the machine components. Then the 14µm-particles should have a value around zero. It could have a large value in the first measurement after a break, but usually it will turn back to zero in a few minutes. If it keeps a larger value for a "long" time, the operator should also check the machine to see whether or not machine maintenance is required. If all the values of different particles have a normal value, the operator should pay attention to the sound of the machine, because in the author's opinion, if some of components are in early stage of failing, the measured data for particles could also remain in a normal state.

4 DISCUSSION AND CONCLUSIONS

4.1 Discussion

The data collected during the field test, are far than enough to make it it possible to find a pattern between particle counter output, machine operations, and machine breaks. So, the discussion will be divided into two parts: one is the relation between particle measurement data and the machine breaks, and the other one is the pattern between particle counter data and machine operations.

4.1.1 Particle measurement and machine operations

Usually most shifting of operation happen in a few seconds, and in some special situations the change of operation might need a few minutes. So, breaks less than five minutes have been chosen and compared with the operations in the same period of time. During the analyzing process, the author found it difficult to find a pattern between these two factors. The particle counter measured the particles each minute, but the operations were recorded each second. The recorded data of the machine operations also showed that the switching of operations could happen in seconds. The amount of time for shifting operation is, thus, almost one over sixty relative to the time interval for the particle measurements. In a time period of 60 seconds, the machine could fell, delimb, and cut a tree into pieces, i.e. the machine operations switch several times, which makes it extremely difficult to find a cause-effect pattern between these factors.

It will be significantly easier to identify a change of the amount of generated particles as an effect of shifting machine operations, if we could shorten the measuring period for the particle counter. There may not be a significant difference in the amount of particles when only one single operation has been shifted, but the combination of several shifting operations could have a significant impact. Consequently, there should be much more work done on analyzing the pattern and relation between particle counter data and machine operations.

4.1.2 Particle measurement and breaks

Basically, the particles are measured with an interval of one minute. If the machine has been stopped or settled down for some reason, then the measurement will be skipped until the machine is turned back into operation. When the machine is stopped, the reasons for it should be stated in an Excel file. If the machine is just in a no-motion status, the operator should document the reasons for them.

The aim for the analysis was to trying to predict the need for machine maintenance based on the measured data. As shown in appendix A, the hydraulic system in the Scorpion King is highly complex. As mentioned in the introduction section, the hydraulic system in the Scorpion King could be divided into five hydraulic subsystems. The scope for this project was focused on the harvester crane subsystem. There could be many reasons for why a machine component suddenly fails. Oil samples have been taken from the transmission line and not directly from the crane tank, which makes it difficult to, based on the available data, indicate which machine subsystem component that is failing and which component that must be serviced or replaced.

Basically, the analysis performed was based on the assumption that the oil sample revealed the state of the oils in the focused subsystem. But, the fluctuation of the data could indicate that this assumption was not correct.

4.2 Conclusions

In the analysis process, the author faced a lot of challenges. At first, the topic of this thesis was discussed a lot with the company Ponsse, Skogforsk, and the supervisors. The tasks were twisted a little bit from the initial purpose. At the beginning, the tasks included an analysis of the existing hydraulic monitoring system, usage of the data from the used device, with an aim to re-design or improve the monitoring system. But after discussions with Ponsse, the tasks were changed to include analysis of the hydraulic system of Scorpion King, analysis of the recorded data from the IcountPDR sensor, and an aim to find the pattern between the measured particles, the machine breaks, and the machine operations.

After the topic was settled, the basic work was targeting the hydraulic system of the Scorpion King. Ponsse supplied the crane system structure including the crane and the harvester head. From the structure, it was easy to find the useful movements of the harvester crane, which could extend, luff, and lift. The harvester head has more functions, include tilting, rotating, feeding trees, and cutting the trees.

Then the operations related to these movements were chosen for the analysis. Because of the differences in measuring periods for the particle counter and the machine operations, it was difficult to find the relation between (combination of) operations and the amount of particles of different sizes in the hydraulic fluid. It would be very helpful if a special field test could be performed, and/or if the sampling rate for the particle measurement could be significantly shortened.

The oil, which was sampled from the transmission line, is a combination of oil from all five subsystems. So, no matter which component it is that is broken, it would be noticed in the measured data, nut it would be impossible to identify which component that should be repaired or replaced.

If the operator could combine information on a sudden “strange” behavior if the particle data with other knowledge or experiences, for example the oil temperature in the tank or the machine sound during operation, it should be easier to identify a need to do pre-maintenance of the machine before an actual failure would actually occur.

5 FUTURE WORK

Based on experiences gained from the analysis process, some improvements of future field tests could be proposed:

1. Firstly, a-two-weeks-long field test is far from enough for a thorough analysis, so it would be better with a significantly longer field test period.

2. The second improvement of the test is the measuring period of the particle counting. As discussed before, the operations of machine has been recorded in each 0.05 second but the measurement of particles are made each minute, the big difference between these measuring period has led the difficulties in analyzing the relations between them. If the particles could be measured in few seconds then the reason for the fluctuating value will be much easier to be found out.

3. A third improvement is focused on the way the field test is performed. In order to find the relations between particle counter results and machine operations, some special tests could be held, like shifting only one of the operations and keeping the others constant. Then the causes for the particle fluctuations could be analyzed.

4. Some of the reasons for breaks that last for less than five minutes should also be recorded. Whenever the operator takes a break which caused a delay of the measurement of particles, the delay should be recorded.

6 REFERENCES

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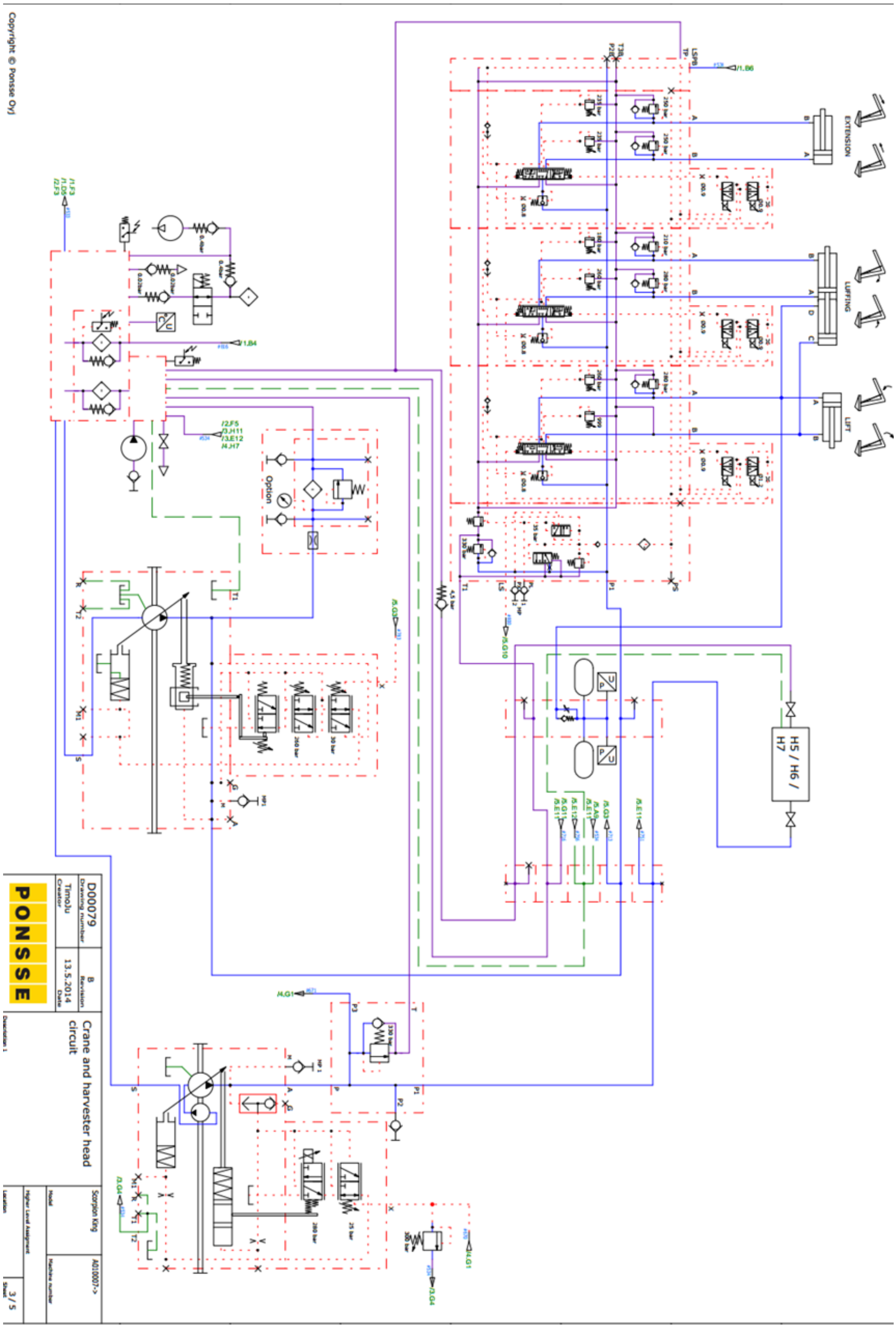
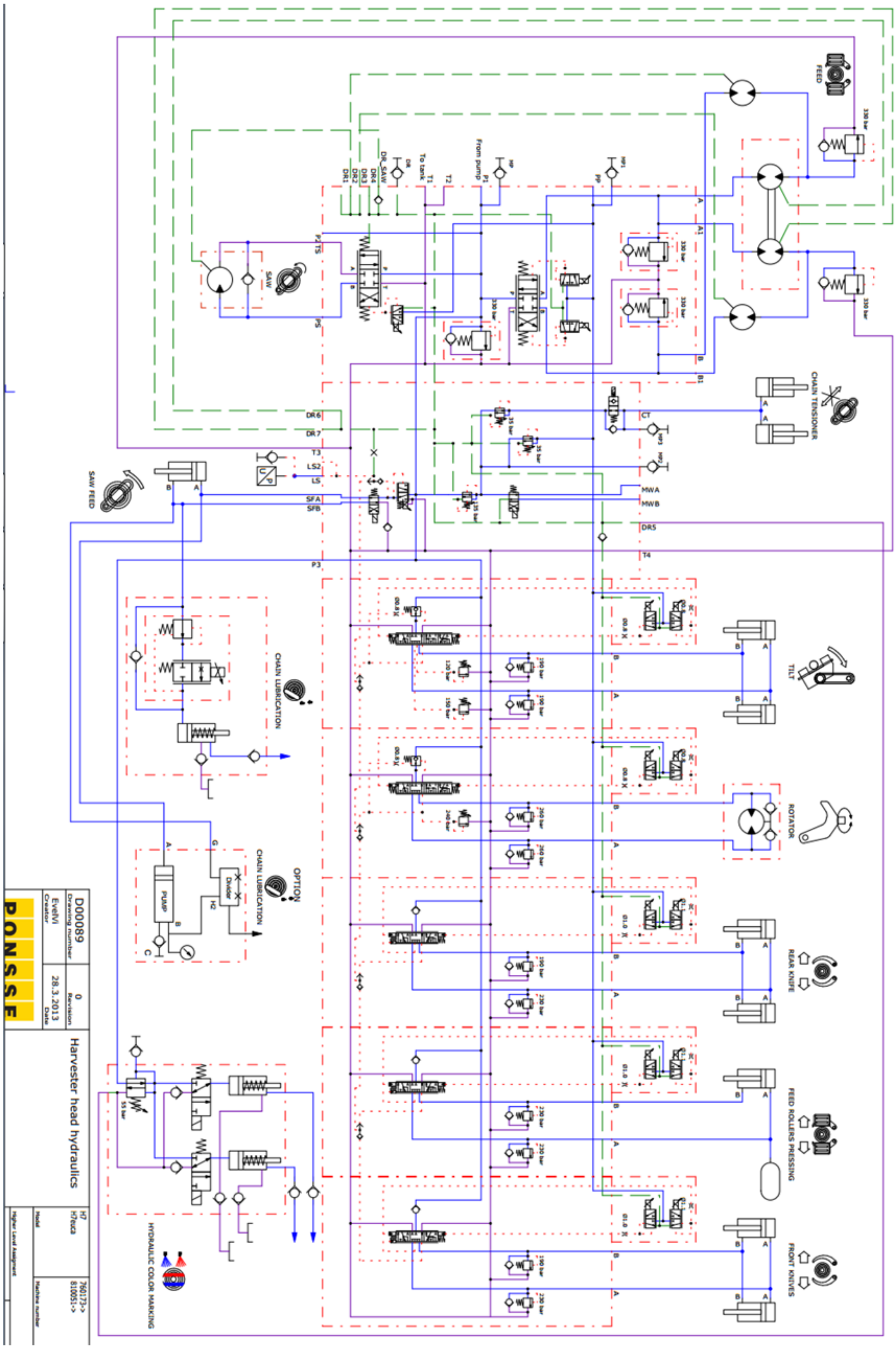
APPENDIX A: HYDRAULIC SYSTEM- CRANE AND HARVESTER HEAD



APPENDIX A: HYDRAULIC SYSTEM- HARVESTER HEAD



APPENDIX B: MATLAB CODE- READ OPERATIONS

```
function datamatrix = load_signal_logger_data( filename )
% Load data from a binary file saved in the Ponsse 'signal logger format' for
Matlab.
%   datamatrix = load_signal_logger_data( filename )
%


%--------------------
% Copyright Creanex Oy, 2015


%---
% Check input arguments


datamatrix = []; % by default the output is an empty matrix


if nargin < 1
    error( 'Input argument ''filename'' must be defined!' );
end
if nargin > 1
    error( 'Too many input arguments!' );
end
if ~isstr(filename)
    error( 'Input argument ''filename'' must be a string!' );
end
if exist(filename) ~= 2
    error( ['The file ''',filename,''' is not found!'] );
end


%---
numColumns = 67;


%---
% Open the file


fid = fopen( filename, 'r' );
if fid == -1
    error( ['Failed to open the file ''', filename,''''] );
end


%---
```

```
% Read data: all bytes to the end of the file

datamatrix = fread( fid, [numColumns,inf], 'float32' ).';

%---
% Close file

retval = fclose( fid );
if retval ~= 0
    error( 'Fatal error: failed to close the opened file' );
end

%--- EOF ---
```

APPENDIX B: MATLAB CODE- PLOTS FOR PARTICLES

```
%% day 02.03.2015
clc
clear
close all
d_02 = xlsread('0203',1);
nr_4mu = d_02(:,1);
nr_6mu= d_02 (:, 2);
nr_14mu = d_02(:,3);
nr_30mu= d_02 (:, 4);
humidity= d_02 (:, 5);
t = 0:1:(length(nr_4mu)-1);
figure
plot(t,nr_4mu,'r');
hold on
plot(t,nr_6mu,'b')
plot(t,nr_14mu,'y')
plot(t,nr_30mu,'g')
plot(t,humidity,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 02/03/2015');

%% day 03.03.2015
d_03 = xlsread('0203',10);
nr_4mu_03 = d_03(:,1);
nr_6mu_03= d_03 (:, 2);
nr_14mu_03 = d_03(:,3);
nr_30mu_03= d_03 (:, 4);
humidity_03= d_03 (:, 5);
t = 0:1:(length(nr_4mu_03)-1);
figure
plot(t,nr_4mu_03,'r');
hold on
plot(t,nr_6mu_03,'b')
plot(t,nr_14mu_03,'y')
plot(t,nr_30mu_03,'g')
plot(t,humidity_03,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
```

```
title('Data for 03/03/2015');

%% day 04.03.2015
d_04 = xlsread('0203',2);
nr_4mu_04 = d_04(:,1);
nr_6mu_04= d_04 (:, 2);
nr_14mu_04 = d_04(:,3);
nr_30mu_04= d_04 (:, 4);
humidity_04= d_04 (:, 5);
t = 0:1:(length(nr_4mu_04)-1);
figure
plot(t,nr_4mu_04,'r');
hold on
plot(t,nr_6mu_04,'b')
plot(t,nr_14mu_04,'y')
plot(t,nr_30mu_04,'g')
plot(t,humidity_04,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 04/03/2015');

%% day 05.03.2015
d_05 = xlsread('0203',3);
nr_4mu_05 = d_05(:,1);
nr_6mu_05= d_05 (:, 2);
nr_14mu_05 = d_05(:,3);
nr_30mu_05= d_05 (:, 4);
humidity_05= d_05 (:, 5);
t = 0:1:(length(nr_4mu_05)-1);
figure
plot(t,nr_4mu_05,'r');
hold on
plot(t,nr_6mu_05,'b')
plot(t,nr_14mu_05,'y')
plot(t,nr_30mu_05,'g')
plot(t,humidity_05,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 05/03/2015');

%% day 06.03.2015
d_06 = xlsread('0203',4);
```

```
nr_4mu_06 = d_06(:,1);
nr_6mu_06= d_06 (:, 2);
nr_14mu_06 = d_06(:,3);
nr_30mu_06= d_06 (:, 4);
humidity_06= d_06 (:, 5);
t = 0:1:(length(nr_4mu_06)-1);
figure
plot(t,nr_4mu_06,'r');
hold on
plot(t,nr_6mu_06,'b')
plot(t,nr_14mu_06,'y')
plot(t,nr_30mu_06,'g')
plot(t,humidity_06,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 06/03/2015');

%% day 09.03.2015
d_09 = xlsread('0203',5);
nr_4mu_09 = d_09(:,1);
nr_6mu_09= d_09 (:, 2);
nr_14mu_09 = d_09(:,3);
nr_30mu_09= d_09 (:, 4);
humidity_09= d_09 (:, 5);
t = 0:1:(length(nr_4mu_09)-1);
figure
plot(t,nr_4mu_09,'r');
hold on
plot(t,nr_6mu_09,'b')
plot(t,nr_14mu_09,'y')
plot(t,nr_30mu_09,'g')
plot(t,humidity_09,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 09/03/2015');

%% day 10.03.2015
d_10 = xlsread('0203',6);
nr_4mu_10 = d_10(:,1);
nr_6mu_10= d_10 (:, 2);
nr_14mu_10 = d_10(:,3);
nr_30mu_10= d_10 (:, 4);
```

```
humidity_10= d_10 (:, 5);
t = 0:1:(length(nr_4mu_10)-1);
figure
plot(t,nr_4mu_10,'r');
hold on
plot(t,nr_6mu_10,'b')
plot(t,nr_14mu_10,'y')
plot(t,nr_30mu_10,'g')
plot(t,humidity_10,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 10/03/2015');

%% day 11.03.2015
d_11 = xlsread('0203',7);
nr_4mu_11 = d_11(:,1);
nr_6mu_11= d_11 (:, 2);
nr_14mu_11 = d_11(:,3);
nr_30mu_11= d_11 (:, 4);
humidity_11= d_11 (:, 5);
t = 0:1:(length(nr_4mu_11)-1);
figure
plot(t,nr_4mu_11,'r');
hold on
plot(t,nr_6mu_11,'b')
plot(t,nr_14mu_11,'y')
plot(t,nr_30mu_11,'g')
plot(t,humidity_11,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 11/03/2015');

%% day 12.03.2015
d_12 = xlsread('0203',8);
nr_4mu_12 = d_12(:,1);
nr_6mu_12= d_12 (:, 2);
nr_14mu_12 = d_12(:,3);
nr_30mu_12= d_12 (:, 4);
humidity_12= d_12 (:, 5);
t = 0:1:(length(nr_4mu_12)-1);
figure
plot(t,nr_4mu_12,'r');
```

```
hold on
plot(t,nr_6mu_12,'b')
plot(t,nr_14mu_12,'y')
plot(t,nr_30mu_12,'g')
plot(t,humidity_12,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 12/03/2015');

%% day 13.03.2015
d_13 = xlsread('0203',9);
nr_4mu_13 = d_13(:,1);
nr_6mu_13= d_13 (:, 2);
nr_14mu_13 = d_13(:,3);
nr_30mu_13= d_13 (:, 4);
humidity_13= d_13 (:, 5);
t = 0:1:(length(nr_4mu_13)-1);
figure
plot(t,nr_4mu_13,'r');
hold on
plot(t,nr_6mu_13,'b')
plot(t,nr_14mu_13,'y')
plot(t,nr_30mu_13,'g')
plot(t,humidity_13,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 13/03/2015');

%% day 16.03.2015
d_16 = xlsread('0203',11);
nr_4mu_16 = d_16(:,1);
nr_6mu_16= d_16 (:, 2);
nr_14mu_16 = d_16(:,3);
nr_30mu_16= d_16 (:, 4);
humidity_16= d_16 (:, 5);
t = 0:1:(length(nr_4mu_16)-1);
figure
plot(t,nr_4mu_16);
hold on
plot(t,nr_6mu_16)
plot(t,nr_14mu_16)
plot(t,nr_30mu_16)
```

```
plot(t,humidity_16)
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 16/03/2015');

%% day 17.03.2015
d_17 = xlsread('0203',12);
nr_4mu_17 = d_17(:,1);
nr_6mu_17= d_17 (:, 2);
nr_14mu_17 = d_17(:,3);
nr_30mu_17= d_17 (:, 4);
humidity_17= d_17 (:, 5);
t = 0:1:(length(nr_4mu_17)-1);
figure
plot(t,nr_4mu_17);
hold on
plot(t,nr_6mu_17)
plot(t,nr_14mu_17)
plot(t,nr_30mu_17)
plot(t,humidity_17)
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 17/03/2015');

%% day 18.03.2015
d_18 = xlsread('0203',13);
nr_4mu_18 = d_18(:,1);
nr_6mu_18= d_18 (:, 2);
nr_14mu_18 = d_18(:,3);
nr_30mu_18= d_18 (:, 4);
humidity_18= d_18 (:, 5);
t = 0:1:(length(nr_4mu_18)-1);
figure
plot(t,nr_4mu_18,'r');
hold on
plot(t,nr_6mu_18,'b')
plot(t,nr_14mu_18,'y')
plot(t,nr_30mu_18,'g')
plot(t,humidity_18,'k')
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 18/03/2015');
```

```
%% day 19.03.2015
d_19 = xlsread('0203',14);
nr_4mu_19 = d_19(:,1);
nr_6mu_19= d_19 (:, 2);
nr_14mu_19 = d_19(:,3);
nr_30mu_19= d_19 (:, 4);
humidity_19= d_19 (:, 5);
t = 0:1:(length(nr_4mu_19)-1);
figure
plot(t,nr_4mu_19);
hold on
plot(t,nr_6mu_19)
plot(t,nr_14mu_19)
plot(t,nr_30mu_19)
plot(t,humidity_19)
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 19/03/2015');

%% day 20.03.2015
d_20 = xlsread('0203',15);
nr_4mu_20 = d_20(:,1);
nr_6mu_20= d_20 (:, 2);
nr_14mu_20 = d_20(:,3);
nr_30mu_20= d_20 (:, 4);
humidity_20= d_20 (:, 5);
t = 0:1:(length(nr_4mu_20)-1);
figure
plot(t,nr_4mu_20);
hold on
plot(t,nr_6mu_20)
plot(t,nr_14mu_20)
plot(t,nr_30mu_20)
plot(t,humidity_20)
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 20/03/2015');

%% day 23.03.2015
d_23 = xlsread('0203',16);
nr_4mu_23 = d_23(:,1);
```

```
nr_6mu_23= d_23 (:, 2);
nr_14mu_23 = d_23(:,3);
nr_30mu_23= d_23 (:, 4);
humidity_23= d_23 (:, 5);
t = 0:1:(length(nr_4mu_23)-1);
figure
plot(t,nr_4mu_23);
hold on
plot(t,nr_6mu_23)
plot(t,nr_14mu_23)
plot(t,nr_30mu_23)
plot(t,humidity_23)
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 23/03/2015');

%% day 24.03.2015
d_24 = xlsread('0203',17);
nr_4mu_24 = d_24(:,1);
nr_6mu_24= d_24 (:, 2);
nr_14mu_24 = d_24(:,3);
nr_30mu_24= d_24 (:, 4);
humidity_24= d_24 (:, 5);
t = 0:1:(length(nr_4mu_24)-1);
figure
plot(t,nr_4mu_24);
hold on
plot(t,nr_6mu_24)
plot(t,nr_14mu_24)
plot(t,nr_30mu_24)
plot(t,humidity_24)
hold off
xlabel('Step time');ylabel('Particle amount');
title('Data for 24/03/2015');
```

APPENDIX C: MEASURED DATA ON 27/03/2015

Fri	Mar	27	05:52:23	2015	25,083333	0,95	22,71667	16,3	12,75	12,75	24,15
Fri	Mar	27	05:53:23	2015	51,666667	1	14,76667	8,533333	0	0	13,15
Fri	Mar	27	05:54:23	2015	25	1	13,26667	6,166667	0	0	14
Fri	Mar	27	05:55:23	2015	25	1	12,45	4,75	0	0	14
Fri	Mar	27	05:56:24	2015	25	1	13	5,716667	0	0	14
Fri	Mar	27	05:57:24	2015	25	1	12,83333	5,583333	0	0	14
Fri	Mar	27	05:58:24	2015	25	1	11,86667	4,783333	0	0	14
Fri	Mar	27	05:59:24	2015	25	1	11	0,866667	0	0	14
Fri	Mar	27	06:00:24	2015	25	1	11,7	5,733333	0	0	13,73333
Fri	Mar	27	06:01:24	2015	25	1	12,13333	5,25	0	0	13
Fri	Mar	27	06:02:24	2015	38,333333	1	13	7,566667	0	0	13
Fri	Mar	27	06:03:24	2015	55,4	1	13	8,7	0	0	13
Fri	Mar	27	06:04:24	2015	25	1	12,1	6,366667	0	0	12,41667
Fri	Mar	27	06:05:24	2015	49,533333	1	12,2	7,966667	0	0	12
Fri	Mar	27	06:06:24	2015	52,2	1	12	8,083333	0	0	12
Fri	Mar	27	06:07:24	2015	55,933333	1	12,01667	8,033333	0	0	11,01667
Fri	Mar	27	06:08:24	2015	35,133333	1	12,33333	6,85	0	0	11
Fri	Mar	27	06:09:24	2015	25	1	11,06667	2,6	0	0	11
Fri	Mar	27	06:10:24	2015	27,133333	1	12,8	3,933333	0	0	11
Fri	Mar	27	06:11:24	2015	34,066667	1	13,01667	7,466667	0	0	10,71667
Fri	Mar	27	06:12:24	2015	37,266667	1	12,01667	6,55	4,416667	0	10,15
Fri	Mar	27	06:13:24	2015	49	1	13,45	8,416667	6,666667	0	10
Fri	Mar	27	06:14:24	2015	25	1	14,23333	6,65	4,65	0	10
Fri	Mar	27	06:15:24	2015	25	1	10,05	3,9	0,3	0	10
Fri	Mar	27	06:16:24	2015	25	1	12,58333	5,833333	2,9	0	10
Fri	Mar	27	06:17:24	2015	25	1	12,51667	6,916667	0,05	0	9,716667
Fri	Mar	27	06:18:24	2015	54,333333	1	14,18333	7,916667	0	0	9,05
Fri	Mar	27	06:19:24	2015	30,333333	1	14,63333	7,483333	0	0	9
Fri	Mar	27	06:20:24	2015	29,266667	1	14,76667	7,35	0	0	9
Fri	Mar	27	06:21:24	2015	25	1	15,95	6,933333	0	0	9
Fri	Mar	27	06:22:24	2015	25	1	12,5	5,55	0	0	9
Fri	Mar	27	06:23:25	2015	25	1	11,11667	4,6	0	0	9
Fri	Mar	27	06:24:25	2015	25	1	13,78333	6,283333	0	0	9
Fri	Mar	27	06:25:25	2015	53,266667	1	15,96667	7,883333	0	0	9
Fri	Mar	27	06:26:25	2015	28,2	1	11,95	2,516667	0	0	9
Fri	Mar	27	06:27:25	2015	25	1	11,31667	0,15	0	0	9
Fri	Mar	27	06:28:25	2015	25	1	12,5	5,966667	0	0	9
Fri	Mar	27	06:29:25	2015	25	1	12,58333	3,566667	0	0	9
Fri	Mar	27	06:30:25	2015	25	1	11,58333	3,033333	0	0	8,25
Fri	Mar	27	06:31:25	2015	25	1	11,15	2,166667	0	0	8,783333
Fri	Mar	27	06:32:25	2015	25	1	13,71667	5,166667	0	0	9
Fri	Mar	27	06:33:25	2015	25	1	14,21667	5,633333	0	0	8,116667
Fri	Mar	27	06:34:25	2015	25	1	13,81667	4,933333	0	0	8
Fri	Mar	27	06:35:25	2015	25	1	12,7	6,233333	0	0	8
Fri	Mar	27	06:36:25	2015	25	1	14,98333	4,65	0	0	8
Fri	Mar	27	06:37:25	2015	25	1	15,33333	3,866667	0	0	8
Fri	Mar	27	06:38:25	2015	25	1	14,21667	4,216667	0	0	8
Fri	Mar	27	06:39:25	2015	54,866667	1	14,93333	7,666667	0	0	8
Fri	Mar	27	06:40:25	2015	27,133333	1	13,63333	3,6	0	0	8
Fri	Mar	27	06:41:25	2015	25	1	14,41667	0,95	0	0	8
Fri	Mar	27	06:42:25	2015	25	1	13	2,5	0	0	8

Fri	Mar	27	06:43:25	2015	14,6	1	9,15	0	0	0	8
Fri	Mar	27	06:44:25	2015	14,333333	1	8,85	0	0	0	8
Fri	Mar	27	06:45:25	2015	25	1	14,53333	0	0	0	8
Fri	Mar	27	06:46:25	2015	25	1	13,13333	0	0	0	8
Fri	Mar	27	06:47:25	2015	30,866667	1	15,06667	2,4	0	0	8
Fri	Mar	27	06:48:25	2015	50,6	1	15,8	8,033333	0	0	8
Fri	Mar	27	06:49:26	2015	25	1	14,33333	0	0	0	8
Fri	Mar	27	06:50:26	2015	25	1	14,05	0,15	0	0	8
Fri	Mar	27	06:51:26	2015	25	1	14,76667	3,666667	0	0	8
Fri	Mar	27	06:52:26	2015	25	1	14,38333	3,933333	0	0	8
Fri	Mar	27	06:53:26	2015	25	1	15,95	6,5	0	0	8
Fri	Mar	27	06:54:26	2015	25	1	14,56667	3,616667	0	0	8
Fri	Mar	27	06:55:26	2015	25	1	14,28333	1,483333	0	0	8
Fri	Mar	27	06:56:26	2015	38,333333	1	15,41667	6,333333	0	0	8
Fri	Mar	27	06:57:26	2015	42,6	1	15,56667	7,166667	0	0	8
Fri	Mar	27	06:58:26	2015	25	1	15,61667	5,983333	0	0	8
Fri	Mar	27	06:59:26	2015	25	1	15,55	6,266667	0	0	8
Fri	Mar	27	07:00:26	2015	25	1	15,78333	6,466667	0	0	8
Fri	Mar	27	07:01:26	2015	25	1	14	5	0	0	8
Fri	Mar	27	07:02:26	2015	25	1	12,88333	1,8	0	0	8
Fri	Mar	27	07:03:26	2015	25	1	12,2	0	0	0	8
Fri	Mar	27	07:04:26	2015	25	1	13,41667	2,733333	0	0	8
Fri	Mar	27	07:05:26	2015	25	1	14,9	5,666667	0	0	8
Fri	Mar	27	07:06:26	2015	25	1	13,46667	0,7	0	0	8
Fri	Mar	27	07:07:26	2015	21,8	1	11,58333	0,65	0	0	8
Fri	Mar	27	07:08:26	2015	25	1	13,16667	2,35	0	0	8
Fri	Mar	27	07:09:26	2015	25	1	14,7	0	0	0	8
Fri	Mar	27	07:10:26	2015	25	1	14,46667	0	0	0	8
Fri	Mar	27	07:11:26	2015	25	1	12,88333	0	0	0	8
Fri	Mar	27	07:12:26	2015	25	1	13,01667	0	0	0	8
Fri	Mar	27	07:13:26	2015	25	1	13,31667	0	0	0	8
Fri	Mar	27	07:14:26	2015	25	1	13,6	1,9	0	0	8
Fri	Mar	27	07:15:27	2015	25	1	13,88333	1,1	0	0	8
Fri	Mar	27	07:16:27	2015	25	1	14,56667	0	0	0	8
Fri	Mar	27	07:17:27	2015	25	1	14,6	0	0	0	8
Fri	Mar	27	07:18:27	2015	25	1	14,75	0	0	0	8
Fri	Mar	27	07:19:27	2015	25	1	14	1,75	0	0	8
Fri	Mar	27	07:20:27	2015	25	1	14,33333	3,6	0	0	8
Fri	Mar	27	07:21:27	2015	25	1	14,41667	1,7	0	0	8
Fri	Mar	27	07:22:27	2015	25	1	12,96667	1,983333	0	0	8
Fri	Mar	27	07:23:27	2015	25	1	8,866667	2,166667	0	0	8
Fri	Mar	27	07:24:27	2015	25	1	11,63333	0	0	0	8
Fri	Mar	27	07:25:27	2015	25	1	14	0	0	0	8
Fri	Mar	27	07:26:27	2015	25	1	12,1	0	0	0	8
Fri	Mar	27	07:27:27	2015	25	1	12,76667	2,433333	0	0	8
Fri	Mar	27	07:28:27	2015	25	1	9,966667	2,566667	0	0	8
Fri	Mar	27	07:29:27	2015	25	1	14,18333	0	0	0	8
Fri	Mar	27	07:30:27	2015	25	1	13,01667	0	0	0	8
Fri	Mar	27	07:31:27	2015	25	1	13,46667	0	0	0	8
Fri	Mar	27	07:32:27	2015	25	1	14,01667	0	0	0	8
Fri	Mar	27	07:33:27	2015	25	1	14,26667	4,4	0	0	8

Fri	Mar	27	07:34:27	2015	25	1	12,81667	1,583333	0	0	8
Fri	Mar	27	07:35:27	2015	24,466667	1	10,38333	0	0	0	8
Fri	Mar	27	07:36:27	2015	15,133333	1	7,533333	0	0	0	8
Fri	Mar	27	07:37:27	2015	23,4	1	11,15	0,5	0	0	8
Fri	Mar	27	07:38:27	2015	25	1	12,98333	2,45	0	0	8
Fri	Mar	27	07:39:27	2015	19,933333	1	8,933333	0	0	0	8
Fri	Mar	27	07:40:27	2015	9	1	6	0	0	0	8
Fri	Mar	27	07:41:28	2015	9	1	6,016667	0	0	0	8
Fri	Mar	27	07:42:28	2015	9	1	4,583333	0	0	0	8
Fri	Mar	27	07:43:28	2015	9	1	5,616667	0	0	0	8
Fri	Mar	27	07:44:28	2015	18,866667	1	10,13333	1,366667	0	0	8
Fri	Mar	27	07:45:28	2015	25	1	14,11667	4,966667	0	0	8
Fri	Mar	27	07:46:28	2015	25	1	13,21667	5,15	0	0	8
Fri	Mar	27	07:47:28	2015	25	1	14,51667	5,466667	0	0	8
Fri	Mar	27	07:48:28	2015	25	1	13,83333	3,35	0	0	8
Fri	Mar	27	07:49:28	2015	25	1	14,81667	0	0	0	8
Fri	Mar	27	07:50:28	2015	25	1	13,9	0	0	0	8
Fri	Mar	27	07:51:28	2015	37,8	1	14,88333	3,2	0	0	8
Fri	Mar	27	07:52:28	2015	43,666667	1	13,91667	5,45	0	0	8
Fri	Mar	27	07:53:28	2015	25	1	15,36667	1	0	0	8
Fri	Mar	27	07:54:28	2015	25	1	15,51667	2	0	0	8
Fri	Mar	27	07:57:35	2015	28,133333	0,93333	42,73333	33,25	30,13333	29,8	36,46667
Fri	Mar	27	07:58:35	2015	57	1	16	13,23333	6,116667	0	8,766667
Fri	Mar	27	07:59:35	2015	57	1	16,78333	10,98333	2,5	0	8,45
Fri	Mar	27	08:00:35	2015	38,866667	1	15,71667	8,333333	0	0	8,733333
Fri	Mar	27	08:01:35	2015	25	1	15,28333	4,6	0	0	9
Fri	Mar	27	08:02:35	2015	25	1	14,03333	2,25	0	0	8,833333
Fri	Mar	27	08:03:35	2015	25	1	11,45	0	0	0	8,383333
Fri	Mar	27	08:04:35	2015	25	1	14,61667	3,316667	0	0	8,416667
Fri	Mar	27	08:05:35	2015	51,666667	1	15,38333	9,15	0	0	8
Fri	Mar	27	08:06:35	2015	42,6	1	14,61667	5,1	0	0	8
Fri	Mar	27	08:07:35	2015	25	1	14,43333	4,816667	0	0	8
Fri	Mar	27	08:08:35	2015	25	1	14,81667	0	0	0	8
Fri	Mar	27	08:09:35	2015	25	1	14,23333	0	0	0	8
Fri	Mar	27	08:10:35	2015	25	1	14,48333	0	0	0	8
Fri	Mar	27	08:11:35	2015	25	1	14,45	3,383333	0	0	8
Fri	Mar	27	08:12:35	2015	25	1	14	3,8	0	0	8
Fri	Mar	27	08:13:35	2015	38,333333	1	15,41667	8,05	0	0	8
Fri	Mar	27	08:14:36	2015	45,8	1	15,28333	8,383333	0	0	8
Fri	Mar	27	08:15:36	2015	25	1	12,26667	2,666667	0	0	8
Fri	Mar	27	08:16:36	2015	20,2	1	7,733333	1,4	0	0	8
Fri	Mar	27	08:17:36	2015	9	1	7	1,6	0	0	8
Fri	Mar	27	08:18:36	2015	40,466667	1	12,48333	5,783333	0	0	8
Fri	Mar	27	08:19:36	2015	37,266667	1	14,8	5,7	0	0	8
Fri	Mar	27	08:20:36	2015	25	1	14,46667	0,4	0	0	8,033333
Fri	Mar	27	08:21:36	2015	25	1	10,78333	0	0	0	8,816667
Fri	Mar	27	08:22:36	2015	25	1	14,08333	0	0	0	8,45
Fri	Mar	27	08:23:36	2015	25	1	16,41667	1,1	0	0	8
Fri	Mar	27	08:24:36	2015	25	1	14,53333	2,483333	0	0	8
Fri	Mar	27	08:25:36	2015	34,066667	1	15,95	7,783333	0	0	8
Fri	Mar	27	08:26:36	2015	25	1	16,43333	4,85	0	0	8

Fri	Mar	27	08:27:36	2015	25	1	17,28333	6,566667	0	0	8
Fri	Mar	27	08:28:36	2015	25	1	17,95	6,466667	0	0	8
Fri	Mar	27	08:29:36	2015	25	1	16,31667	4,7	0	0	8
Fri	Mar	27	08:30:36	2015	25	1	13,93333	1,1	0	0	8
Fri	Mar	27	08:31:36	2015	25	1	16,68333	5,25	0	0	8
Fri	Mar	27	08:32:36	2015	25	1	16,16667	4,966667	0	0	8
Fri	Mar	27	08:33:36	2015	25	1	17,01667	6	0	0	8
Fri	Mar	27	08:34:36	2015	37,266667	1	18	7,516667	0	0	8
Fri	Mar	27	08:35:36	2015	57	1	18	9,95	0	0	8
Fri	Mar	27	08:36:36	2015	57	1	17,53333	11	0	0	8
Fri	Mar	27	08:37:36	2015	57	1	17	11,81667	0	0	8
Fri	Mar	27	08:38:36	2015	57	1	16,65	11,23333	0	0	8
Fri	Mar	27	08:39:36	2015	57	1	17,73333	12,41667	0	0	8
Fri	Mar	27	08:40:37	2015	57	1	18	13	0	0	8
Fri	Mar	27	08:41:37	2015	57	1	17,03333	12,95	1,35	0	8
Fri	Mar	27	08:42:37	2015	57	1	17	12,21667	1,65	0	8
Fri	Mar	27	08:43:37	2015	57	1	17,48333	12,76667	0	0	8
Fri	Mar	27	08:44:37	2015	57	1	17,78333	12,88333	0	0	8
Fri	Mar	27	08:45:37	2015	57	1	18,3	14,63333	2,533333	0	8
Fri	Mar	27	08:46:37	2015	57	1	17,63333	13,33333	6,666667	0	8
Fri	Mar	27	09:44:02	2015	53,2	0,93333	32,41667	25,68333	20,41667	17	24,46667
Fri	Mar	27	09:45:02	2015	19,933333	1	23,23333	17,2	12,8	12,8	21,71667
Fri	Mar	27	09:46:02	2015	43,666667	1	13,58333	7,633333	2,316667	0	10
Fri	Mar	27	09:47:02	2015	37,8	1	13,61667	6,933333	2,716667	0	10
Fri	Mar	27	09:48:02	2015	25	1	13,55	5,866667	0	0	10
Fri	Mar	27	09:49:02	2015	25	1	15,81667	4,45	0	0	10
Fri	Mar	27	09:50:02	2015	28,733333	1	16,76667	7,133333	0,85	0	9,733333
Fri	Mar	27	09:51:02	2015	44,2	1	17	7,916667	2,25	0	9
Fri	Mar	27	09:52:02	2015	57	1	15,58333	9,316667	2,8	0	9
Fri	Mar	27	09:53:02	2015	57	1	15,01667	9,05	0	0	9
Fri	Mar	27	09:54:02	2015	47,933333	1	13,78333	8,9	0	0	9
Fri	Mar	27	09:55:02	2015	25	1	10,71667	5,766667	0	0	9
Fri	Mar	27	09:56:02	2015	25	1	12	6,55	0	0	9
Fri	Mar	27	09:57:02	2015	25	1	12,9	6,95	0	0	9
Fri	Mar	27	09:58:02	2015	25	1	13,06667	6,75	0	0	9
Fri	Mar	27	09:59:02	2015	25	1	11,98333	5,916667	0	0	9
Fri	Mar	27	10:00:02	2015	37,266667	1	14,68333	7,55	0	0	8,65
Fri	Mar	27	10:01:02	2015	57	1	14,51667	9,366667	0	0	8
Fri	Mar	27	10:02:02	2015	26,6	1	10,7	1,733333	0	0	8
Fri	Mar	27	10:03:02	2015	14,6	1	7,783333	0	0	0	8
Fri	Mar	27	10:04:02	2015	9	1	6,466667	0	0	0	8
Fri	Mar	27	10:05:03	2015	9	1	6,8	0	0	0	8
Fri	Mar	27	10:06:03	2015	12,466667	1	6,8	1,4	0	0	8
Fri	Mar	27	10:07:03	2015	25	1	9,516667	5,033333	0	0	8
Fri	Mar	27	10:08:03	2015	25	1	9,516667	2,4	0	0	8
Fri	Mar	27	10:09:03	2015	25	1	10,73333	4,133333	0	0	8
Fri	Mar	27	10:10:03	2015	25	1	9,733333	2,533333	0	0	8
Fri	Mar	27	10:11:03	2015	25	1	10,86667	4,633333	0	0	8
Fri	Mar	27	10:12:03	2015	12,466667	1	7,416667	0	0	0	8
Fri	Mar	27	10:13:03	2015	9	1	7	0	0	0	8
Fri	Mar	27	10:14:03	2015	23,933333	1	8,833333	0	0	0	8

Fri	Mar	27	10:15:03	2015	13,266667	1	7,7	0	0	0	8
Fri	Mar	27	10:16:03	2015	20,733333	1	9,133333	0	0	0	8
Fri	Mar	27	10:18:20	2015	21,733333	0,93333	41,31667	31,6	29,8	29,8	36,46667
Fri	Mar	27	10:19:21	2015	56,466667	1	16	11,45	0	0	8
Fri	Mar	27	10:20:21	2015	57	1	16	10,11667	0	0	8
Fri	Mar	27	10:21:21	2015	27,666667	1	14,95	7,3	0	0	8,133333
Fri	Mar	27	10:22:21	2015	25	1	13,28333	2,533333	0	0	8,266667
Fri	Mar	27	10:23:21	2015	25	1	13,08333	0	0	0	8
Fri	Mar	27	10:24:21	2015	25	1	15,08333	0	0	0	8
Fri	Mar	27	10:25:21	2015	25	1	15,73333	2	0	0	8
Fri	Mar	27	10:26:21	2015	25	1	13,21667	4,05	0	0	8,1
Fri	Mar	27	10:27:21	2015	25	1	10,33333	2,4	0	0	8,316667
Fri	Mar	27	10:28:21	2015	25	1	11	0	0	0	8
Fri	Mar	27	10:29:21	2015	25	1	13,88333	1,4	0	0	8
Fri	Mar	27	10:30:21	2015	25	1	13,36667	1,6	0	0	8
Fri	Mar	27	10:31:21	2015	25	1	13,91667	0	0	0	8
Fri	Mar	27	10:32:21	2015	25	1	15,01667	0	0	0	8
Fri	Mar	27	10:33:21	2015	25	1	10,51667	0	0	0	8
Fri	Mar	27	10:34:21	2015	25	1	9,633333	0,75	0	0	8
Fri	Mar	27	10:35:21	2015	25	1	14,93333	2,25	0	0	8
Fri	Mar	27	10:36:21	2015	25	1	13,33333	0	0	0	8
Fri	Mar	27	10:37:21	2015	25	1	14,11667	0	0	0	8
Fri	Mar	27	10:38:21	2015	25	1	14,31667	2,9	0	0	8
Fri	Mar	27	10:39:21	2015	25	1	13,8	0,9	0	0	8
Fri	Mar	27	10:40:21	2015	25	1	13,75	2,15	0	0	8
Fri	Mar	27	10:41:21	2015	25	1	13,36667	0	0	0	8
Fri	Mar	27	10:44:19	2015	22	0,93333	40,25	27,66667	27,66667	27,66667	34,46667
Fri	Mar	27	10:45:19	2015	54,066667	1	18,31667	13,78333	2,133333	2,133333	10,66667
Fri	Mar	27	10:46:19	2015	39,4	1	17	8,45	0	0	8,35
Fri	Mar	27	10:47:19	2015	25	1	17	5,483333	0	0	8
Fri	Mar	27	10:48:19	2015	25	1	16,25	6,416667	0	0	8
Fri	Mar	27	10:49:19	2015	25	1	13,38333	4,316667	0	0	8,933333
Fri	Mar	27	10:50:19	2015	25	1	11,95	0	0	0	9
Fri	Mar	27	10:51:19	2015	25	1	10,83333	4,866667	0	0	9
Fri	Mar	27	10:52:19	2015	19,666667	1	9,083333	0,55	0	0	8,75
Fri	Mar	27	10:53:19	2015	25	1	11,71667	2,65	0	0	8
Fri	Mar	27	10:54:19	2015	25	1	12,98333	1,15	0	0	8
Fri	Mar	27	10:55:19	2015	25	1	11,66667	1,85	0	0	8
Fri	Mar	27	10:56:19	2015	25	1	14,6	1,35	0	0	8,466667
Fri	Mar	27	10:57:20	2015	24,466667	1	12,71667	1,6	0	0	8,65
Fri	Mar	27	10:58:20	2015	25	1	13,13333	0	0	0	8,15
Fri	Mar	27	10:59:20	2015	25	1	13,33333	2,6	0	0	8
Fri	Mar	27	11:00:20	2015	25	1	13,61667	2,15	0	0	8
Fri	Mar	27	11:01:20	2015	25	1	13,33333	2,466667	0	0	8,483333
Fri	Mar	27	11:02:20	2015	25	1	14,16667	3,783333	0	0	8
Fri	Mar	27	11:03:20	2015	25	1	11,1	1,7	0	0	8
Fri	Mar	27	11:04:20	2015	14,333333	1	7,6	0	0	0	8
Fri	Mar	27	11:05:20	2015	25	1	10,71667	2,5	0	0	8
Fri	Mar	27	11:06:20	2015	25	1	13,8	6,283333	0	0	8
Fri	Mar	27	11:07:20	2015	25	1	15,28333	6,733333	0	0	8
Fri	Mar	27	11:08:20	2015	25	1	14,86667	5,766667	0	0	8

Fri	Mar	27	11:09:20	2015	25	1	13,73333	0,65	0	0	8
Fri	Mar	27	11:10:20	2015	25	1	13,86667	3,233333	0	0	8
Fri	Mar	27	11:11:20	2015	25	1	13,83333	1,6	0	0	8
Fri	Mar	27	11:12:20	2015	25	1	14,95	4,366667	0	0	8
Fri	Mar	27	11:13:20	2015	25	1	15,31667	6,316667	0	0	8
Fri	Mar	27	11:14:20	2015	25	1	16,05	5,616667	0	0	8
Fri	Mar	27	11:15:20	2015	25	1	12,21667	1,8	0	0	8
Fri	Mar	27	11:16:20	2015	25	1	15,71667	0	0	0	8
Fri	Mar	27	11:17:20	2015	48,466667	1	15,56667	7,45	0	0	8,866667
Fri	Mar	27	11:18:20	2015	26,6	1	13,5	3,166667	0	0	8,7
Fri	Mar	27	11:19:20	2015	25	1	14	1,35	0	0	8
Fri	Mar	27	11:20:20	2015	25	1	15,26667	1,65	0	0	8
Fri	Mar	27	11:21:20	2015	24,466667	1	11,35	0,7	0	0	8
Fri	Mar	27	11:22:20	2015	20,733333	1	11,35	2,25	0	0	8
Fri	Mar	27	11:23:21	2015	25	1	13,88333	0	0	0	8
Fri	Mar	27	11:24:21	2015	25	1	12,38333	2,3	0	0	8
Fri	Mar	27	11:25:21	2015	25	1	13,78333	0,65	0	0	8
Fri	Mar	27	11:31:40	2015	32,4	0,93333	41,23333	34,43333	29,8	29,8	36,55
Fri	Mar	27	11:32:40	2015	57	1	16,96667	11,86667	2,516667	0	9
Fri	Mar	27	11:33:40	2015	57	1	16	11,28333	4,95	0	9
Fri	Mar	27	11:34:40	2015	31,4	1	15,3	2,266667	0,1	0	8,933333
Fri	Mar	27	11:35:40	2015	25	1	12,36667	2	0	0	8,766667
Fri	Mar	27	11:36:40	2015	25	1	12,65	1	0	0	8,966667
Fri	Mar	27	11:37:40	2015	25	1	14,23333	0	0	0	8
Fri	Mar	27	11:38:40	2015	25	1	13,35	0	0	0	8
Fri	Mar	27	11:39:40	2015	25	1	13,93333	0	0	0	8
Fri	Mar	27	11:40:40	2015	25	1	14,91667	0	0	0	8
Fri	Mar	27	11:41:40	2015	25	1	15,05	0,6	0	0	8
Fri	Mar	27	11:42:40	2015	25	1	14,78333	2,65	0	0	8
Fri	Mar	27	11:43:41	2015	24,466667	1	10,21667	2,7	0	0	8
Fri	Mar	27	11:44:41	2015	25	1	14,45	4,3	0	0	8
Fri	Mar	27	11:45:41	2015	25	1	15,4	4,733333	0	0	8
Fri	Mar	27	11:46:41	2015	25	1	15,73333	5,966667	0	0	8
Fri	Mar	27	11:47:41	2015	25	1	12,85	2,25	0	0	8
Fri	Mar	27	11:48:41	2015	25	1	12,9	0	0	0	8
Fri	Mar	27	11:49:41	2015	25	1	13,95	0	0	0	8
Fri	Mar	27	11:50:41	2015	25	1	16,51667	0	0	0	8
Fri	Mar	27	11:51:41	2015	25	1	16,3	0	0	0	8
Fri	Mar	27	11:52:41	2015	25	1	14,38333	2,733333	0	0	8
Fri	Mar	27	11:53:41	2015	25	1	12,23333	3,366667	0	0	8
Fri	Mar	27	11:54:41	2015	25	1	12,83333	0	0	0	8
Fri	Mar	27	11:55:41	2015	25	1	13,11667	0	0	0	8
Fri	Mar	27	11:56:41	2015	25	1	14,28333	0	0	0	8
Fri	Mar	27	11:57:41	2015	25	1	14,53333	0	0	0	8
Fri	Mar	27	11:58:41	2015	25	1	12,26667	0,7	0	0	8
Fri	Mar	27	11:59:41	2015	25	1	13,8	2,25	0	0	8
Fri	Mar	27	12:00:41	2015	25	1	13,78333	0	0	0	8
Fri	Mar	27	12:01:41	2015	25	1	15,2	0	0	0	8
Fri	Mar	27	12:02:41	2015	25	1	11,48333	2,95	0	0	8
Fri	Mar	27	12:03:41	2015	25	1	14	3,416667	0	0	8
Fri	Mar	27	12:04:41	2015	25	1	13,93333	5,366667	0	0	8

Fri	Mar	27	12:05:41	2015	12,466667	1	7,866667	0,5	0	0	8
Fri	Mar	27	12:06:41	2015	9	1	6,583333	0	0	0	8
Fri	Mar	27	12:07:41	2015	22,6	1	12,3	0,8	0	0	8
Fri	Mar	27	12:08:42	2015	25	1	13,73333	2,2	0	0	8
Fri	Mar	27	12:09:42	2015	25	1	13,61667	0	0	0	8
Fri	Mar	27	12:10:42	2015	25	1	13,4	4,416667	0	0	8
Fri	Mar	27	12:11:42	2015	25	1	14,63333	5,4	0	0	8
Fri	Mar	27	12:12:42	2015	25	1	13,16667	2,85	0	0	8
Fri	Mar	27	12:13:42	2015	25	1	13,58333	2,683333	0	0	8
Fri	Mar	27	12:14:42	2015	25	1	13,93333	7,516667	0	0	8
Fri	Mar	27	12:15:42	2015	25	1	15,06667	5,783333	0	0	8
Fri	Mar	27	12:16:42	2015	25	1	15,18333	5,633333	0	0	8
Fri	Mar	27	12:17:42	2015	34,6	1	14,15	6,1	0	0	8
Fri	Mar	27	12:18:42	2015	47,933333	1	14,95	8,666667	0	0	8
Fri	Mar	27	12:19:42	2015	25	1	12,08333	1,516667	0	0	8
Fri	Mar	27	12:20:42	2015	25	1	14,41667	0	0	0	8
Fri	Mar	27	12:21:42	2015	25	1	16	0	0	0	8
Fri	Mar	27	12:22:42	2015	25	1	14,28333	1,15	0	0	8
Fri	Mar	27	12:23:42	2015	25	1	12,91667	4,583333	0	0	8
Fri	Mar	27	12:24:42	2015	25	1	13,45	5,45	0	0	8
Fri	Mar	27	12:25:42	2015	25	1	12,95	2,716667	0	0	8
Fri	Mar	27	12:26:42	2015	25	1	14,63333	1	0	0	8
Fri	Mar	27	12:27:42	2015	25	1	14,73333	0	0	0	8
Fri	Mar	27	12:28:42	2015	25	1	13,93333	2	0	0	8
Fri	Mar	27	12:29:42	2015	23,4	1	11,55	0,95	0	0	8
Fri	Mar	27	12:30:42	2015	22,066667	1	10,4	0,266667	0	0	8
Fri	Mar	27	12:31:42	2015	25	1	14,5	3,966667	0	0	8
Fri	Mar	27	12:32:42	2015	25	1	15	6,55	0	0	8
Fri	Mar	27	12:33:42	2015	25	1	14,56667	6,6	0	0	8
Fri	Mar	27	12:34:43	2015	31,933333	1	15,9	7,383333	0	0	8
Fri	Mar	27	12:35:43	2015	25	1	11	1,716667	0	0	8
Fri	Mar	27	12:36:43	2015	25	1	14,26667	5,6	0	0	8
Fri	Mar	27	12:37:43	2015	25	1	13,75	4,816667	0	0	8
Fri	Mar	27	12:38:43	2015	25	1	13,73333	2,983333	0	0	8
Fri	Mar	27	12:39:43	2015	20,2	1	11,45	1,85	0	0	8
Fri	Mar	27	12:42:02	2015	32,4	0,93333	42,46667	35,5	29,8	29,8	36,76667
Fri	Mar	27	12:43:02	2015	46,866667	1	15,21667	8,666667	0	0	9
Fri	Mar	27	12:44:02	2015	25	1	14,06667	4,833333	0	0	8,416667
Fri	Mar	27	12:45:02	2015	25	1	14,56667	5,316667	0	0	8
Fri	Mar	27	12:46:02	2015	25	1	13,9	2,516667	0	0	8
Fri	Mar	27	12:47:02	2015	25	1	16,08333	1,2	0	0	8
Fri	Mar	27	12:48:02	2015	25	1	15,55	2,1	0	0	8
Fri	Mar	27	12:49:02	2015	25	1	14,83333	2,7	0	0	8
Fri	Mar	27	12:50:02	2015	25	1	16,01667	2,2	0	0	8
Fri	Mar	27	12:51:02	2015	25	1	17,73333	6,916667	0	0	8
Fri	Mar	27	12:52:02	2015	25	1	17,46667	6,8	0	0	8
Fri	Mar	27	12:53:02	2015	25	1	16,55	4,3	0	0	8
Fri	Mar	27	12:54:02	2015	25	1	16	0	0	0	8
Fri	Mar	27	12:55:02	2015	25	1	16,36667	0,5	0	0	8
Fri	Mar	27	12:56:02	2015	49	1	16,93333	8,283333	0	0	8
Fri	Mar	27	12:57:02	2015	33	1	12,51667	5,216667	0	0	8
Fri	Mar	27	12:58:03	2015	25	1	13,11667	0,85	0	0	8
Fri	Mar	27	12:59:03	2015	25	1	17	0	0	0	8
Fri	Mar	27	13:00:03	2015	25	1	17	0	0	0	8
Fri	Mar	27	13:01:03	2015	25	1	17	0	0	0	8
Fri	Mar	27	13:02:03	2015	25	1	17	0	0	0	8

APPENDIX D: TECHNICAL SPECIFICATION OF ICOUNTPDR

Technical specification

Feature	Specification
Product start-up time	5 seconds minimum
Measurement period	5–180 seconds
Reporting interval	0–3600 seconds via RS232 communication
Principle of operation	Laser Diode optical detection of actual particulates
International codes	ISO 7 – 22, NAS 0 – 12
Calibration	By recognised online methods confirmed by the relevant ISO procedures: **MTD** – via a certified primary ISO 11171 automatic particle detector using ISO 11943 principles, with particle distribution reporting to ISO 4406:1996
Recalibration	Contact Parker Hannifin
Working pressure	2–420 bar (30–6000 PSI)
Flow range through icountPDR	**Note**: Flow may be bi-directional 40–140 ml/min (optimum flow 60 ml/min) (0.01 – 0.04 USGPM (optimum flow 0.016 USGPM))
Online flow range via System 20 sensors	Size 0 = 6 to 25 l/min (2–7 USGPM) Size 1 = 24 to 100 l/min (6–26 USGPM) Size 2 = 170 to 380 l/min (45–100 USGPM)
Ambient storage temperature	–40°C to +80°C (–40°F to +176°F)
Environment operating temperature	-30°C to +60°C (–22°F to 140°F)
Fluid operating temperature	+5°C to +80°C (+41°F to 176°F)
Computer compatibility	Parker recommends the use of a 9-way D-type connector. This can be connected to a USB port using a USB-serial adaptor. Note that these connectors/adaptors are **NOT** supplied with icountPDR units: contact Parker Hannifin for advice.
Moisture sensor calibration	±5% RH (over compensated temperature range of +10°C to +80°C; +50°F to +176°F)
Operating humidity range	5% RH to 100% RH
Moisture sensor stability	±0.2% RH typical at 50% RH in one year
Power requirement	Regulated 9–40Vdc
Current rating	Typically 120mA
Certification	IP69K rating EC Declaration of Conformity (see page 4).
Analogue output options (specified when ordering)	
Variable current	4–20mA
Variable voltage	0–5Vdc, 0–3Vdc (user selectable)
CAN-bus	to SAE J1939 (e.g. *Parker IQAN*)
Moisture sensor	Linear scale within the range 5% RH to 100% RH